CHAPTER 9. CLOTHES WASHER SHIPMENTS MODEL: REVISED MODEL

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CHAPTER 9. CLOTHES WASHER SHIPMENTS MODEL: REVISED MODEL

9.1 OVERVIEW

Clothes washer shipment estimates are a necessary input for manufacturer impact analysis and national energy savings calculations. In the Advanced Notice of Proposed Rulemaking (ANOPR), we examined several different approaches to forecasting new washer sales. The investigated models include an Auto-Regressive Moving Average Model (ARIMA), a Multi-Variate Time Series Fit, a Saturation/Lifetime Model, and an Accounting Model with elasticity. Of the different approaches, we selected the Accounting Model because it was the most full-featured model which included price and operating cost elasticities.

In this chapter, we describe a revised accounting model for projecting annual clothes washer shipments that includes the following factors:

- combined effects of price, operating cost, features and other macroeconomic explanatory variables (income, credit, etc.) on annual U.S. shipments
- market segments (e.g., new housing and moves, replacement decisions, non-owner adding a washer)
- decisions to repair rather than replace
- purchases of used washers
- age categories of clothes washers

This Clothes Washer Shipments Model incorporates information from the DOE Consumer Analysis. Since the ANOPR, DOE has gathered additional information about features of clothes washers that influence consumers' purchase decisions, and analyzed consumer's stated preferences. This new information also has been calibrated with updated information about historical purchases.

9.1.1 Definition of Market Segments and Ownership Categories in the Shipments Model

This clothes washer shipments model described in this chapter segments both clothes washer owners (i.e. households) and clothes washer purchases into different categories. The different types of clothes washer owners include (1) new housing and housing purchases, (2) existing housing with a regular[a] washer, (3) housing without a washer, and (4) housing with an extended life washer. We refer to the population of clothes washers in each ownership category as the *stock* of clothes washers of that category.

The different types of clothes washer owners are faced with different clothes washer purchase decisions and purchase motivations. The reason for buying a clothes washer determines the *Market*

[a]Regular meaning a washer that has not undergone an "extended repair."

Segment that the purchase represents. The different types of clothes washer purchases are divided into six separate market segments as follows:

1. New Housing and Housing Purchases Market: When there is a net increase in the housing stock, a housing purchase or changes of residence, the increase in the number of households or the changes of residence may force the purchase of a new clothes washer.

2. Early (Discretionary) Replacement Market: Even before a clothes washer breaks down, about 27% of clothes washer owners replace the existing clothes washer because they want an updated model, because of remodeling, or for other miscellaneous reasons.

3. Regular Replacement Market: Most clothes washer purchases result from the replacement of an existing washer that has broken down after the completion of its useful life.

4. Extra Repair Market: Under conditions of high costs for new clothes washers a few consumers will rebuild or repair a broken down washer (thus extending its lifetime) rather than purchasing a new clothes washer. Eventually, even extended life washers break down and are replaced.

5. Non-owner to owner conversion market: A few households without a clothes washer will purchase a clothes washer and become new clothes washer owners.

6. Used clothes washer purchases market: For many clothes washer purchases, the consumer will have the additional decision of whether to purchase a new or used machine. There is a significant used clothes washer market (18% of total sales) that can interact with the market for new clothes washer purchases.[1]

Figure 9.1 shows the structure of the model. The boxes represent the different types of clothes washer owners and households, while the diamonds represent the different decisions that are made by the consumer and how the results of the decisions feed into other elements of the model.

In the model, the stock of existing washers is categorized in terms of ownership or household category. Several different types of owners may participate in a particular market segment, and each ownership category may participate in one to several market segments. Each market segment is modeled by a probability function which represents the likelihood of a particular consumer decision. Economic decision variables (such as price, operating cost savings and the features available for new clothes washers) influence the magnitude of these decision probabilities.

The clothes washer shipments model keeps track of the population of each type of clothes washer and clothes washer purchase. The model is run with an annual time step. Thus, annual purchases represent the incremental changes in clothes washer stocks for each time period. The flow diagram in Figure 9.1 represents the process of taking an initial stock of washers of the four different categories, calculating the purchases induced by this initial stocks of clothes washers, and calculating the new stock levels that result. The rectangles represent the different ownership categories, the arrows represent the stock flows of clothes washer households, and the diamonds represent the decisions that these households are making in the course of a year.

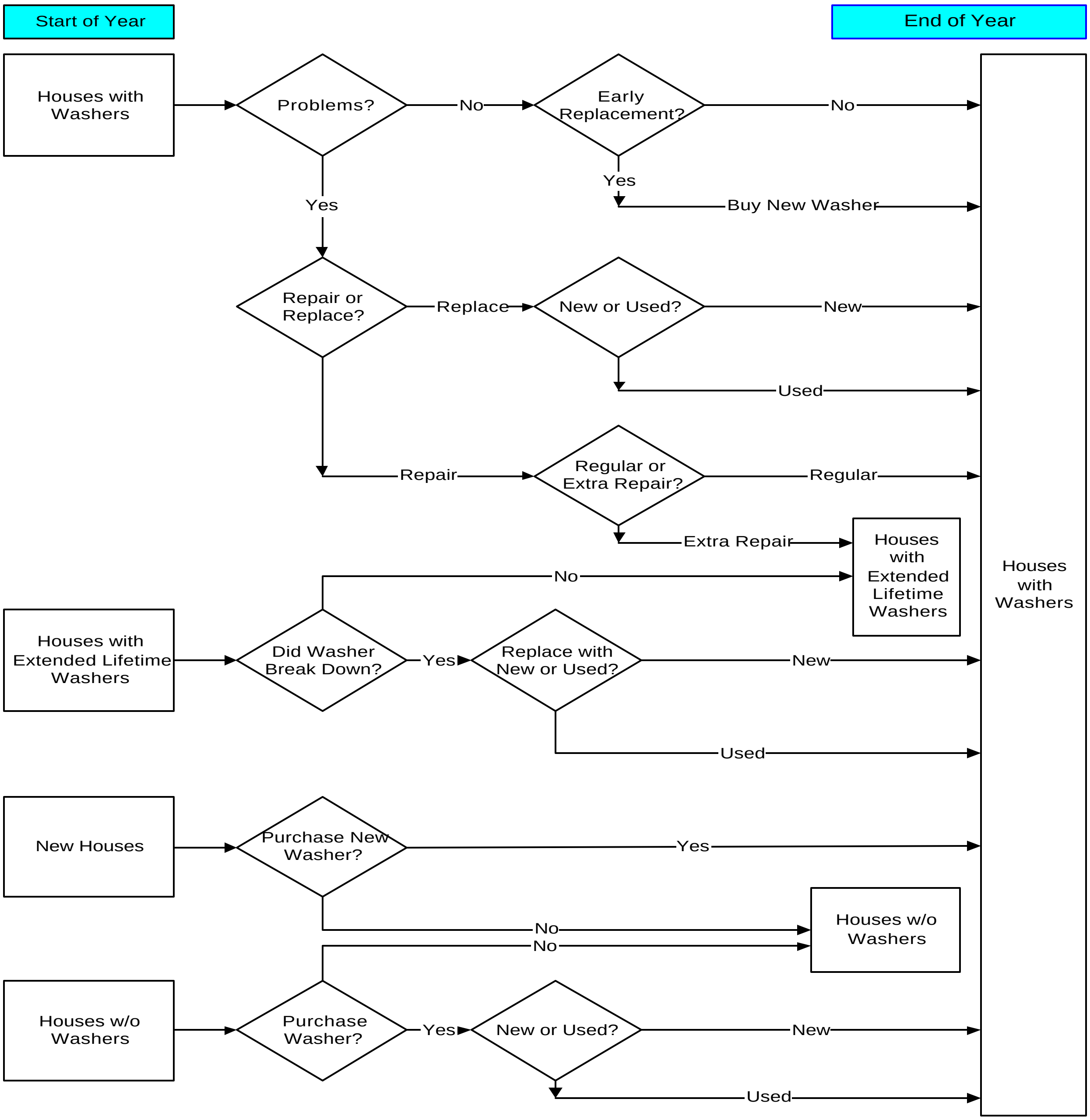

Figure 9.1 Flow Diagram for Clothes Washer Shipments Model

To carry out one year's calculation, one starts in a rectangle with the amount of clothes washers in that category. Then one flows out in the direction of the arrow until one arrives at a diamond that represents a decision. For each decision there is an inflow of one arrow and an outflow of two arrows. One apportions the stock according to the probability function that describes the proportion of washers that are subjected to each outcome. One keeps flowing through the diagram until one arrives back at a shaded rectangle that represents a stock category. The result is the number of washers that have flowed from one stock to another stock in the course of one year. To get the total stock at the end of the year, one adds up the contribution from all possible flow diagram paths. In the model this process is repeated each year until the year 2030.

Consumer decisions influence how the stock and supply of clothes washers flow from one category to another. Decisions which are economically influenced are modeled with econometric equations. The parameters of these econometric equations are calibrated with industry statistics on historic shipments and are also calibrated with market information from both the AHAM survey[1] and the Clothes Washer Consumer Analysis.[2]

The decisions to which each category of households (and their clothes washers) are subjected are described below:

Net new households and housing moves are those households that must make a clothes washer purchase decision because of a change in residence. These households are faced with the decision of whether or not to get a new clothes washer with the house that they move into. A consumer is faced with this decision when he or she moves into a house without a washer and was not able to take his or her old washer to the new residence.

For households with existing regular washers, the first question is whether or not the current washer is having operational problems (i.e. needs repair). If the washer is without problems then the consumer must decide if he or she wants to purchase a washer for other discretionary reasons. If the washer has operational problems, then the consumer must decide if the washer is to be repaired or replaced. If the consumer makes an extra repair, one which avoids the purchase of a new washer, then the model assumes that that repair extends the washer lifetime by 6 years.

For households without washers a small fraction (at most a few percent) of consumers will decide to become clothes washer owners. Those who become owners will do so by purchasing either a new or used clothes washer.

Households with extended lifetime washers are those households that have extended the lifetime of their washer through an extra repair when the washer last broke down. If the clothes washer breaks down yet again, the consumer will have to have it replaced with either a new or used machine.

In Section 1.1.2 we compare the current modeling approach with the models that were examined in the ANOPR analysis. In Section 1.1.3 we review the economics durables sales forecasting literature; Section 1.2 describes the details of the mathematical structure of the model, while Section 1.3 discusses the modeling of economic consumer decisions, and Section 1.4 presents the model results.

9.1.2 Recent Enhancements of Shipments Model

Since publication of the Technical Support Document (TSD)[3] for the Advanced Notice of Proposed Rulemaking, we have made several improvements to the clothes washer shipments forecast. These improvements include the following:

Detailed accounting of different market segments and washer ownership categories: Previous shipments models accounted for only the new clothes washer market and the replacement market. The previous model assumed that a washer was replaced by a new washer when it broke down. The current model now accounts for a variety of other market dynamics including options to purchase new vs. used washers, changes in repair behavior, and extending the life of washers through extra repairs.

Price and operating cost elasticities calibrated to historical data: The model now includes consumer responsiveness to price and operating costs calibrated to historical clothes washer shipments. The operating cost response relative to the price sensitivity is calibrated to 1997 purchase decisions and the current engineering analysis.

Consumer response to the front-loading feature is included: The model includes a consumer response to whether top-loading machines are available. Elasticity with regards to the front-loading vs top-loading feature is adapted from the recent Clothes Washer Consumer Analysis.

Removal of the income elasticity: We assumed no income elasticity, for consistency with the Clothes Washer Consumer Analysis.

Utilization of a wide variety of data sources: The current shipments model utilizes a wide range of information to make the model reflect current consumer and market characteristics:

- Clothes Washer Consumer Analysis results for both the relative size of consumers response to features relative to their response to price and operating expense, and to estimates of the rate at which clothes washer owners might drop out of the market.
- AHAM survey data on the proportion of early (discretionary) replacements, on the proportion of new vs. used purchases, and the proportion of sales associated with a change in residence.

- AHAM statistics on historical shipments and on the recent (post 1994 standard) changes in mean clothes washer efficiency.
- *Consumer Reports* data on repair rates of washers.

The purpose of these model enhancements is to provide the best estimates possible for future clothes washer shipments that are consistent with the recent history of washer shipments, and with current clothes washer market structure and consumer preferences.

9.1.3 Review of Other Published Research

We performed a review of recent literature on forecasting purchases of consumer durables in order to evaluate studies regarding price and features sensitivities and their application to long term sales forecast models. We report on eight relevant studies published from 1990 to the present.

In this literature, a standard measure of consumer sensitivity to features of the products and the market is sales *elasticity*. Elasticity is the parameter that relates the relative change in sales relative to a change in a feature (such a price, ***P***). For example:

$$e = (\Delta S / S) \big/ (\Delta P / P) \qquad \textbf{Eq. 9-1}$$

where $\boldsymbol{\Delta S/S}$ is the relative change in sales, $\boldsymbol{\Delta P/P}$ is the relative change in price, and $\boldsymbol{\varepsilon}$ is the elasticity. Elasticities are generally negative numbers ranging from 0 to -3. A product which has an elasticity -2 will experience a 2% drop in sales for a 1% increase in price.

According to the marketing and sales forecasting literature, consumer price response and elasticity varies dramatically depending on the type of trade-offs being made, the time scale over which sales variations are being measured, the type of durable being examined and the stage of development of the particular durables market in question.[4, 5, 6, 7]

The greatest price sensitivity is observed when consumers are being asked to make trade-offs between price, brand, and features in an unconstrained market where the consumer has the choice of different brands and makes of product. In this context, which is most relevant to marketing decisions, the choice of from whom to buy a product is highly sensitive to the price being charged by a particular manufacturer. Price/features trade-offs are typically applied to set prices for different product classes according to the overall value that consumers place on other features relative to price (e.g. Dolan, 1996[8]).

In the long-term sales forecast literature, elasticities are much smaller than those observed in short term sales or product choice applications. These differences in estimated elasticity reflect the difference between a long-term perspective (whether to own a washer) and a short-term one (which washer to purchase and when to buy). Furthermore, durables undergo a time dependent price sensitivity as they go from introduction to acceptance in the overall market.[6, 7, 9] Research that examines the change in elasticities over time[9] finds that for clothes dryers and appliances that are deemed 'necessities' (i.e. have a high market penetration) that 'elasticities are either constant, not statistically different from zero, or decline toward the later stages of the adoption life cycle.[9] These results are based on fitting models with elasticity, to the historical data on shipments and sales of major appliances.

Since the introduction of standards could potentially cause long-term structural changes in prices and features, we consider the results from the long-term sales forecast literature most relevant to the present clothes washer shipments modeling effort. It is expected that elasticities will be smaller than what is found when consumers are evaluating brand or features choices. Calibrating elasticities to fit historical sales data is present practice in the long-term sales forecast modeling literature.

9.2 METHOD

9.2.1 Definitions

The model is organized in terms of three classes of items: Stocks, Events, and Decisions. These different classes are defined as follows.

9.2.1.1 Stock

A **Stock** is the number of households with a particular washer of a particular ownership category. The main property of a stock is that it evolves over the course of the year by aging one year and by increasing or decreasing in response to inflows and outflows produced by events and decisions. The four permanent stocks in the model are new households, households with washers, the households without washers, and households with rebuilt or extended-life washers. In addition to the permanent stocks, there are temporary stocks of washers in need of repair, repaired washers, rebuilt washers, washers purchases used, and retired washers. All of the temporary stocks are allocated to one of the four permanent stocks within the one year computational time step of the model.

9.2.1.2 Events

Events are things that happen to a stock that can change the status of a portion of that stock, but do not depend on economic conditions. Events do not depend on market conditions, but are dependent on the properties of the stock. The main event in the model is washer problem development or breakdown. For regular clothes washers, whether or not a washer develops problems that require a repair is an event. For extended-life washers, whether the washer suffers from a final breakdown is another event.

9.2.1.3 Decisions

Decisions are consumer reactions to events and market conditions. Decisions are described in terms of probabilities that typically depend on the type of stock, the age of the clothes washer, the incremental cost of the decision, and market conditions. The probability of two subsequent decisions in the same year is equal to the product of the two individual decision probabilities. The dependence of decision probabilities on price and market conditions is given by a standard econometric logit equation:

$$\ln\left(\mathrm{Prob}/\left(1-\mathrm{Prob}\right)\right)=\mathbf{a}+\mathbf{b}*\left(Price\right)+\mathbf{c}*\left(Operating\ Cost\right)+\mathbf{d}*\left(Feature\ Index\right)$$ **Eq. 9-2**

where Prob is the probability of the decision, and where the right hand side of the equation represents the utility of the decision. The coefficients **b, c,** and **d** represent sensitivities that the consumer has for the different aspects of the economic decision. For the sensitivity cases that we examine, we also include other economic decision parameters like income, interest rate, and the price/income ratio. The constant term **a** is an offset for the utility which calibrates the utility to the value of the market share in a reference year. These coefficients are determined through a combination of assumptions about consumer behavior, based upon studies regarding consumer preferences, and model calibration with historic shipments data.

The details of model calibration and selection of parameters for the consumer decision model are presented in Section 1.3 on modeling economic decisions.

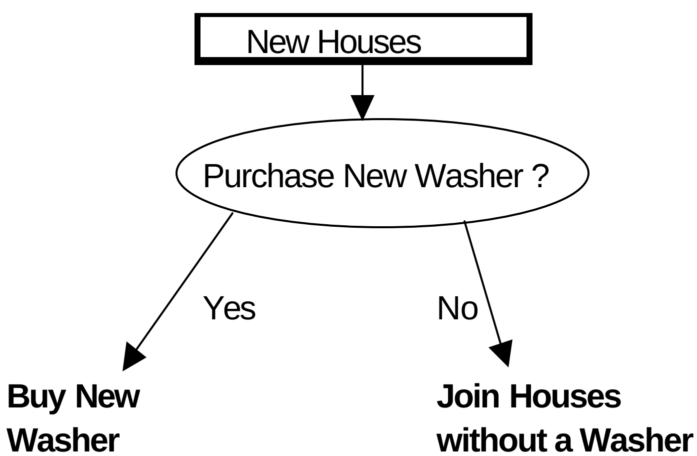

Figure 9.2 Decision Tree for New Housing and Housing Moves

9.2.2 Purchases from New Housing and Housing Moves

9.2.2.1 Definition

Purchases from new housing and housing moves are defined as those new purchases that arise from changes in residence.

9.2.2.2 Approach

The decision tree shown in Figure 9.2 illustrates the approach taken or modeling these purchases.

Data is available for the market saturation of new households with washers up to 1994. This market share is projected into the future using a logit probability of purchase equation as described in Section 1.3. This same market saturation is applied to a market that consists of moves between existing housing. The moves market is assumed to correlate with the new housing market in size and its magnitude is set so that the sum of this market and the new housing market is consistent with AHAM data[1] on the fraction of clothes washer purchases obtained due to changes of residence (25% of all purchases).

The equations for estimating the purchases from new housing are as follows:

$$\begin{aligned} CW_{New/New\ Homes} &= Prob_{New\ Homes} \cdot (\Delta\ House_{stock} + MovesMarket) \\ CW_{Used/New\ Homes} &= 0 \end{aligned} \qquad \textbf{Eq. 9-3}$$

where:

$CW_{New/NewHomes}$	=	New clothes washer purchase for new homes
$Prob_{New\ Homes}$	=	The probability of purchase of washers for new homes
$\Delta House_{stock}$	=	The net increase in housing
MovesMarket	=	The market of moves between existing housing.
$CW_{Used/NewHomes}$	=	Used clothes washer purchases for new homes (assumed 0).

9.2.2.3 Current Assumptions.

The model assumes that purchases from new housing and moves arise from two related sources. One source is moves into new housing which is measured by new housing completions, while the second is a related market of moves between existing housing. We assume that the size of the move related market is correlated with new housing construction, and we calibrate the size of this market by enforcing the condition that move-related sales consist of 25% of all sales between 1990 and 1996 consistent with

AHAM survey data. In this market segment we accounted for only new clothes washer sales, since a used washer sale is equivalent to just moving an existing washer from one house to another.

9.2.3 Existing Housing with Regular Washers

9.2.3.1 Definition

Existing housing with "regular" clothes washers are those existing households that have a washing machine, and whose washing machine has not had an extra repair that extends the life of the clothes washer.

9.2.3.2 Approach

The decisions involved with the replacement and repair of regular washers in existing housing are illustrated in Figure 9.3. The figure shows that several decisions and events affect the replacement of an existing washer with a new or used machine.

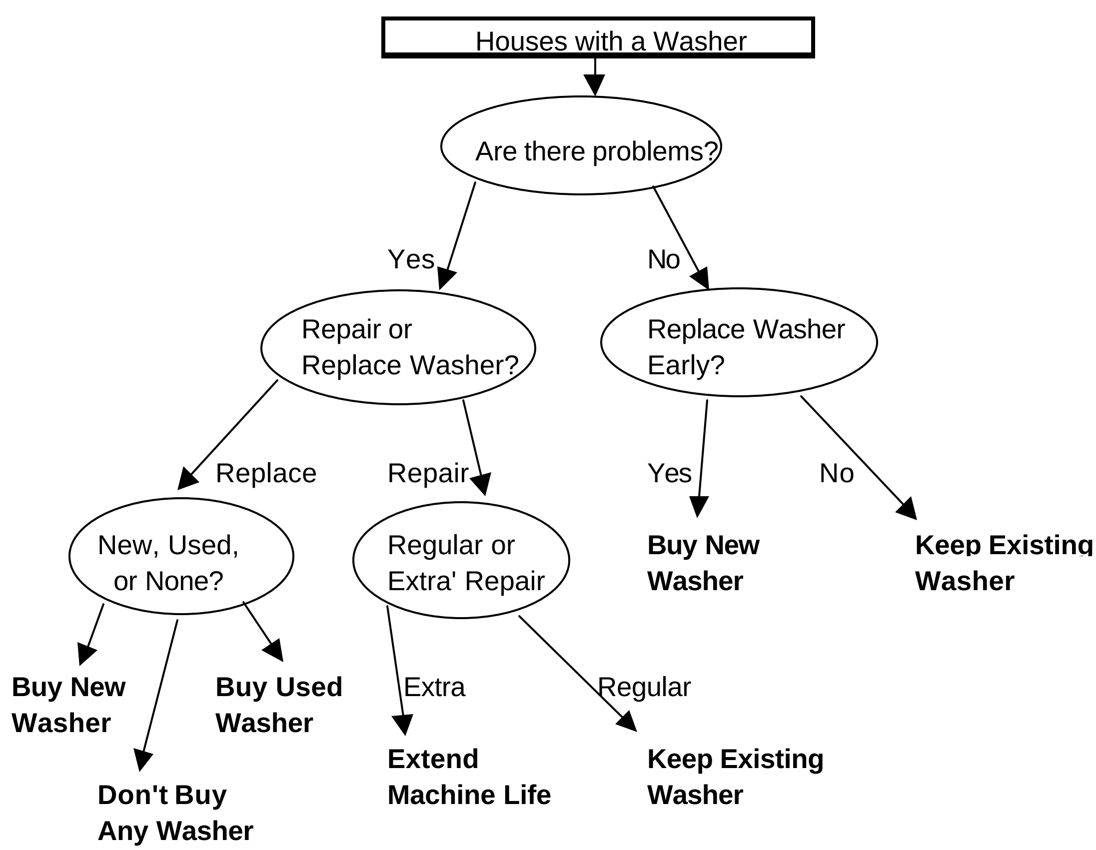

Figure 9.3 Decision Tree for Replacement and Repair of Regular Washers in Existing Housing

For a household with an existing washing machine, the first question is whether or not the clothes washer has problems and needs repair. If the washer needs repair, the consumer will then decide whether to repair the machine or replace it. If the machine is replaced, then there is the decision of whether to get a new or used machine, or to do without a clothes washer (according to the Clothes Washer Consumer Analysis, about 2% of current clothes washer owners will consider doing without a washer). If the machine is repaired, then the decision is evaluated to see if it is an 'extra' repair for a machine that under normal economic conditions would have been replaced. If it is an extra repair, then the washer is assumed to have its life extended by 6 years.

If the machine does not have any problems, the consumer still may replace the washer early (before breakdown). According to AHAM survey data, about 27% of clothes washers are replaced early. These discretionary purchases are referred to as *early replacements*.

The decisions and events in the decision tree are modeled with probability functions. We therefore need five relative probability functions to model this purchase decision process:

1. The probability that an existing washer has a problem
2. The probability of replacing, or repairing a machine as a function of age.
3. The probability of a used/new purchase.
4. The probability of an early replacement of a machine without problems.
5. The probability that a washer is not replaced.

1. *<u>The probability that an existing washer has a problem</u>* is a function with a 5% annual repair rate for the first five years, increasing linearly with age, and a 100% needs-repair rate at 17 years. To do this we assume that the relative probability that a surviving machine required repairs is 5%. So we have:

$$\textit{Probability of Needs-Repair} = C * \textit{age} * \textit{Probability of Survival} \qquad \textbf{Eqn. 9-4}$$

Where C is chosen so that the probability of a repair in the first five years averages 5% per year. This function is independent of time. The survival function for a clothes washer is derived from the replacement function used in the ANOPR analysis, and is illustrated in Figure 9.4.

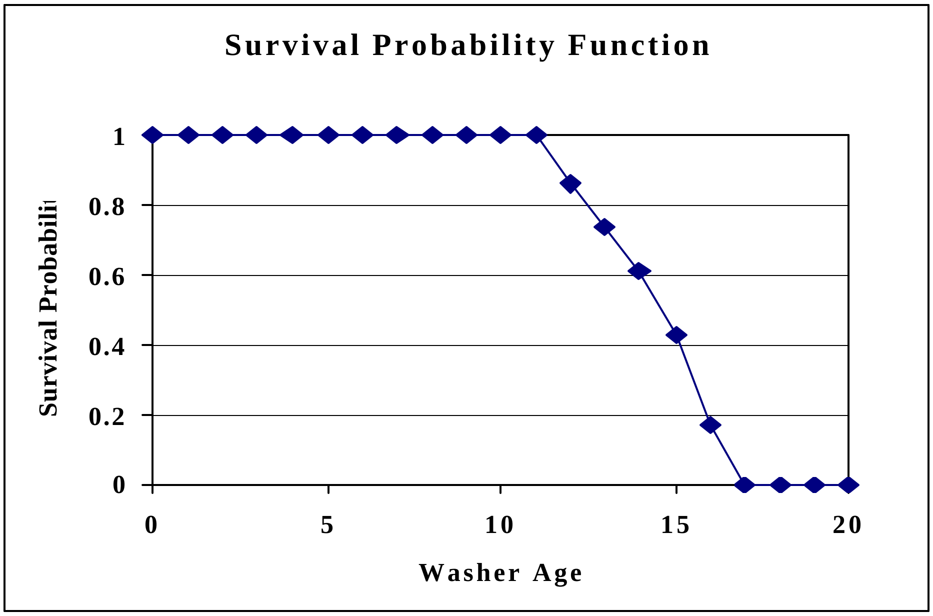

Figure 9.4 Probability of Survival for Regular Clothes Washer

2. *The probability of Repair vs. Replace* (replace and retire are used interchangeably) is subject to market variations and changes as described by a probability of purchase equation:

$$\text{Prob}_{\text{Repair vs. Retire}}\left(year, age\right) = Probability\ of\ \ Repair\ vs.Retire = \left(\text{Probability of Needs– Repair}\right)\Big/\left[1-\left(\text{Probability of Survival}\right)\right] \quad \textbf{Eq. 9-5}$$

If more machines are being repaired instead of retired, we extend the life of the repaired machine by 6 years. In the model, this clothes washer machine life extension is implemented by moving the machine to the stock of extended lifetime machines, and using a survival probability function for this stock which is shifted by six years.

3. AHAM survey data provides *the relative proportion of new vs. used purchases*. We use this proportion, and project it into the future using a probability of purchase model. When a used purchase is made, we assume that the age distribution of used machines is the same as the age distribution of the used machine supply resulting from discretionary replacements.

4. For *the probability of early retirement*, a simple linear function describes the relative probability of a discretionary clothes washer replacement over time. This function is assumed to be 0 at age 0 and to

increase linearly with clothes washer age. The slope of this function is chosen so that the relative proportion of discretionary replacements vs. all replacements in the model output is consistent with AHAM data (i.e. 27% in 1996). Clothes washer purchases that result from a change of residence are not considered to be 'replacements.'

5. *The probability that a machine is not replaced at breakdown* is fixed at 2%, based upon interview results from the Clothes Washer Consumer Analysis.

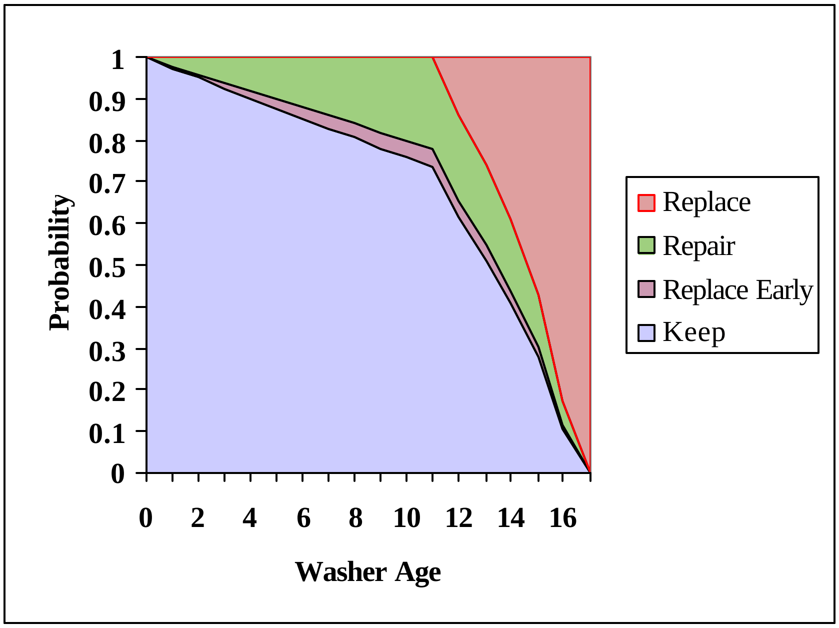

Figure 9.5 Relative Probability of Regular Replacement, Repair, Early Replacement and No Action as a Function of Clothes Washer Age for 1997

Figure 9.5 shows the probabilities for the different decisions and events as a function of clothes washer age for the model calibration year of 1997. For most of the age of the washer, the most likely disposition of an existing clothes washer is for it to be kept. There is a significant probability of repairs for much of the machine's life. Meanwhile as the clothes washer becomes old the likelihood of replacement becomes dominant. Throughout the clothes washers' life, there is some probability of an early replacement. Though in any given year the probability of an early replacement may be small, the cumulative effect of this small probability is approximately 27% of total clothes washer sales.

The equations describing the details of the disposition of the existing washers are as follows:

$$CW_{NeedsRepair}(year, age) = Prob_{NeedsRepair}(year, age) * CW_{Stock}(year, age) \quad \textbf{Eq. 9-6}$$

$$CW_{Retired}(year, age) = Prob_{Retire vs. Repair}(year, age) * CW_{NeedsRepair}(year, age) \quad \textbf{Eq. 9-7}$$

$$CW_{Early}(year, age) = Prob_{Early}(year, age) * \left(CW_{Stock}(year, age) - CW_{NeedsRepair}(year, age)\right) \quad \textbf{Eq. 9-8}$$

$$Prob_{XtraRepairs}(year, age) = Prob_{Retire vs. Repair}(year, age) - Prob_{Retire vs. Repair}(1996, age) \quad \textbf{Eq. 9-9}$$

$$CW_{XtraRepairs}(year, age) = Prob_{XtraRepairs}(year, age) * CW_{NeedsRepair}(year, age) \; (\text{if } Prob_{Xra\ Repairs} > 0 \text{ else } CW_{XtraRepairs} = 0) \quad \textbf{Eq. 9-10}$$

where

$CW_{Needs\text{-}Repair}$(year, age)	=	The number of regular washers of a given age that need repairs in a given year.
$Prob_{Needs\text{-}Repair}$(age)	=	The probability that a regular washer of a given age needs repair (this function is independent of year).
CW_{Stock}(year, age)	=	The number of regular washers of a particular age in a given year.
$CW_{Retired}$ (year, age)	=	The number of regular washers retired.
$Prob_{Retire\ vs\ Repair}$ (year, age)	=	The relative probability that a regular washer which needs repair will be retired.
CW_{Early} (year, age)	=	The number of washers that are replaced early.
$Prob_{Early}$ (year, age)	=	The probability that a washer will be replaced early.
$Prob_{Xtra\ Repairs}$ (year, age)	=	The probability that a regular washer received extra repairs that extended its lifetime.
$CW_{Xtra\ Repairs}$ (year, age)	=	The number of regular washers that received lifetime-extending repairs.

9.2.3.3 Current Assumptions

There are several important assumptions made in modeling the replacement and repair of existing clothes washers. These include:

1. The needs-repair (or problems) probability function is independent in time.

2. For a clothes washer which is not retired in 1997, the probability that a clothes washer needs repair is zero when the machine is new, and increases linearly with clothes washer age. The mean annual probability that a washer needs repair in the first five years is 5%.

3. The probability that a broken down machine is not replaced is fixed at 2%.

4. All early replacements result in the purchase of a new machine.

5. The probability of a regular replacement and the probability of a new vs. used purchase are independent: For example, the probability of a regular replacement with a used machine is the probability of replacement times the probability of purchasing a used machine.

6. If a greater proportion of machines with problems obtain repairs in the future than they did in 1996, then the additional population of repaired machines have an extended lifetime which is 6 years greater than the regular washer lifetime.

7. For machines that do not experience problems, the relative probability of an early replacement is zero for a new machine and increases linearly with washer age.

9.2.4 Households without Clothes Washers

9.2.4.1 Definition

Households without clothes washers are those households that do not have a clothes washer within the residence. This is equal to the number of households minus the number of households with clothes washers.

9.2.4.2 Approach

The approach taken to model purchase decisions by households without clothes washers is shown in Figure 9.6. First the household decides if it is going to purchase a clothes washer, and if so it then decides whether or not to purchase new or used.

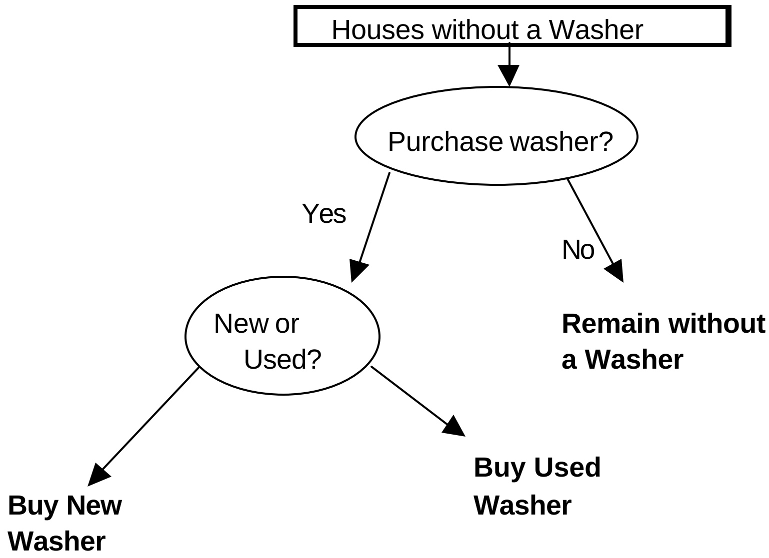

Figure 9.6   Decision Tree for Housing Without a Washer

We assume an annual probability of purchase (relatively small) which varies according to the economic probability of purchase model. We also use the ratio of new vs. used purchase probability which is calibrated with market conditions in 1997 to be consistent with AHAM data.

The relatively simple dynamics of the decision by a non-owner household deciding to buy a washer is described by one equation:

$$CW_{NoWasherToWasher}(year) = Prob_{NoWasherToWasher}(year) \cdot CW_{NoWasherStock}(year) \qquad \textbf{Eq. 9-11}$$

where:

$CW_{\text{No Washer to Washer}}$ (year)	=	The number of non-owner households that purchase clothes washers in a given year.
$Prob_{\text{No Washer to Washer}}$ (year)	=	The probability that a non-owner household will purchase a clothes washer in a given year.
$CW_{\text{No Washer Stock}}$ (year)	=	The number of non-owner households in a given year.

And the number of non-owner households is calculated from the existing housing stock and the number of clothes washer owners as described in the following equation:

$$\mathrm{CW}_{\mathrm{NoWasherStock}}(year) = (\mathrm{HousingStock})(year) - \sum[\mathrm{CW}_{\mathrm{Stock}}](year) \qquad \textbf{Eq. 9-12}$$

9.2.4.3 Current Assumptions

The main assumption is that the probability of purchase from a non-owner household is very small. Secondly it is assumed that the new vs. used decision probability is the same as it is with the regular washer owners. And finally we assume that the different probabilities are independent; i.e., the probability of two decisions or events is the product of the individual event /decision probabilities.

9.2.5 Households with Extended-Life Washers

9.2.5.1 Definition

These households have clothes washers that received more repairs than was normal in the reference year of 1996. It is therefore assumed that the lifetime of these clothes washers has been extended by these extra repairs.

9.2.5.2 Approach

The input of this particular stock of washers comes from regular washer households that have made extra repairs on their washing machines. Once an extra repair has been made, it is assumed that no more repairs will be made after the next machine breakdown.

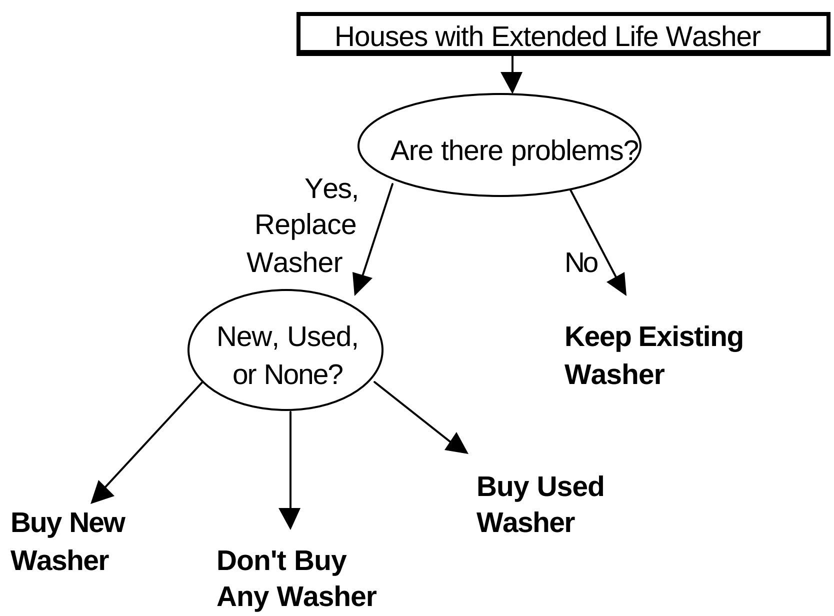

Figure 9.7 Decision Tree for Housing with Extended-Life Clothes Washers

Figure 9.7 illustrates the decision tree for the stock of extended-life clothes washers. Note that these washers are already quite old because they are regular washers that have received extra repairs near breakdown (between 11 and 17 years of age). The main event in this decision tree is whether or not the machine has problems. This probability function is a shifted version of the survival probability function for regular washers; it is illustrated in Figure 9.8.

Besides the survival probability function, the decision of whether a machine is replaced with a new washer, a used washer, or no washer is the same as that for regular washers.

In terms of equations, the dynamics of the extended-life clothes washers can be described as follows: First the retirement of the clothes washers is calculated simply with the retirement (replacement) probability function (shown in Figure 9.8).

$$CW-XR_{Retired}(\text{year},\text{age}) = Prob_{XR_{Retire}}(\text{age}) * CW - XR_{Stock}(\text{year},\text{age})$$ **Eqn. 9-13**

Then the stock accounting is done such that the change in stock is the number of regular clothes washers that get extra repairs minus the stock that is returned:

where:

$$CW-XR_{Stock}(year, age) = CW-XR_{Stock}(year-1, age-1) - CW-XR_{Retired}(year-1, age-1) + CW_{XtraRepairs}(year-1, age-1)$$ **Eq. 9-14**

CW-XR $_{Retired}$ (year, age)	=	The number of extended-life clothes washers of a particular age retired in a given year.
Prob $_{XR\text{-}Retire}$(age)	=	The probability that an extended-life washer of a given age will be replaced or retired.
CW-XR $_{Stock}$(year, age)	=	The number of extended-life washers of a given age in a given year.
CW $_{Xtra\ Repairs}$ (year, age)	=	The number of regular washers of a particular age that received extra repairs in a given year.

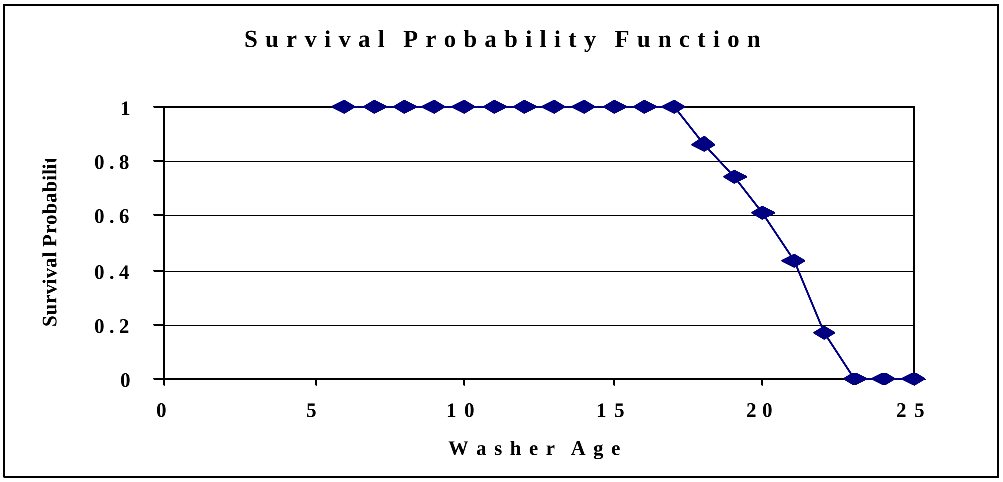

Figure 9.8 Survival Probability Function for Extended Lifetime Washers

9.2.5.3 Current Assumptions

There are several assumption of the extended-life clothes washer modeling. These assumptions include:

1. Extended life washers are never repaired again.
2. The extended-life washers have a lifetime that is 6 years greater than that of the regular washers.
3. The new vs. used vs. no replacement decision has the same relative probabilities as in the regular washer case.
4. The different probabilities are independent, that is the probability of two events or decisions is the product of the individual probabilities.
5. The retirement probability function is independent of time.

9.2.6 Accounting Equations

For making the shipment forecasts, we specify a series of equations that define the dynamics and accounting of the different types of clothes washer stocks. For net new housing the equation describing the stock of new housing is straight forward. The stock of new housing is the difference between the current year housing stock and the previous year's housing stock. Meanwhile the most complicated accounting equation is that which describes the accounting of the existing stock of regular washers.

For the stock of regular washers we have two equations which describe the accounting of the population. The first equation says that the number of one-year old clothes washers is equal the number of new clothes washers purchased the previous year:

$$\mathrm{CW}_{\mathrm{Stock}}(year, age = 1) = \mathrm{CW}_{\mathrm{New}}(year - 1) \qquad \textbf{Eq. 9-15}$$

Meanwhile the next equation describes the accounting for washers of the different, older age categories:

$$\begin{aligned} CW_{Stock}(year, age) = {} & CW_{Stock}(year-1, age-1) - CW_{Retired}(year-1, age-1) - \\ & CW_{Early}(year-1, age-1) - CW_{XtraRepairs}(year-1, age-1) + \\ & \left(CW_{Used}(year-1) \Big/ \sum [CW_{Early}]\right) * CW_{Early}(year-1, age-1) \end{aligned} \quad \textbf{Eq. 9-16}$$

where

year	=	The year that the stock is being estimated.
CW_{Stock} (year, age)	=	The population of regular clothes washers in existing housing of a particular age.
CW_{New} (year)	=	The number of new washer purchases in a particular year.
$CW_{Retired}$(year, age)	=	The number of regular washers from a particular age category that were replaced in a given year because of problems that had occured.
CW_{Early} (year, age)	=	The number of regular washers that are replaced early from a particular age category in a given year for discretionary reasons.
CW_{Used}(year)	=	The total number of used purchases in a given year.
S [CW_{Early}](year)	=	The total number of early replacements (of all age categories) of regular washers in a given year.
$CW_{Xtra\ Repairs}$ (year, age)	=	The number of regular washers that have received lifetime-extending repairs. These washing machines get transferred to the extended lifetime stock.

Equation 16 indicates that the number of clothes washers in a particular age category is equal to the number of clothes washers in the younger age category of the previous year minus the number of clothes washers retired or replaced early and plus the number of used clothes washers of that age category that have been purchased in the previous year. The age distribution of used clothes washers is assumed to be the same as the age distribution of clothes washers that are replaced early (since such early replacements are assumed to provide much of the used clothes washer supply).

Then for the stock accounting for the extended life machines (those that have received extra repairs), we have the following:

$$\begin{aligned} CW\!-\!XR_{Stock}(year, age) = {} & CW\!-\!XR_{Stock}(year-1, age-1) - CW\!-\!XR_{Retired}(year-1, age-1) + \\ & CW_{XtraRepairs}(year-1, age-1) \end{aligned} \quad \textbf{Eq.9-17}$$

where

$CW\text{-}XR_{Stock}$ (year, age)	=	The number of clothes washers in a given year of a given age group that belong to the stock of machines that have received extra repairs. These extra repairs have extended the life of the machine.
$CW\text{-}XR_{Retired}$(year, age)	=	The number of machines of a particular age that are retired from the extra repair stock in a given year.
$CW_{Xtra\ Repairs}$ (year, age)	=	The number of regular washers of a particular age in a given year that receive repairs that extend the machine life in a given year.

Equation 17 says that the stock of extended life clothes washers comes from regular washers which receive extra repairs when they break down. This stock then ages, and is removed as it is retired due to additional repair problems.

For the stock of households with no washer we have the following equation:

$$CW_{No\ Washer\ Stock}(year) = (\text{Housing Stock})(year) - \sum [CW_{Stock}](year) - \sum [CW - XR_{Stock}](year) \qquad \textbf{Eq. 9-18}$$

where

$CW_{No\ Washer\ Stock}$(year)	= The stock of households who do not own clothes washers
(Housing Stock) (year)	= The total stock of housing in a given year
$\Sigma[CW_{Stock}]$(year)	= The total stock of houses with regular clothes washers of any age category.
$\Sigma[CW\text{-}XR_{Stock}]$(year)	= The total stock of houses with extended life washers of any age category.

Equation 18 says that number of non-owner households is the number of households minus the number of regular washer owners minus the number of extended life washer owners.

The new and used washer purchase are related to changes in the different clothes washer stocks as follows:

$$CW_{New}(\text{year}) = Prob_{New\ Vs.\ Used}(\text{year}) * \left\{ \sum \left[0.98 * \begin{pmatrix} CW_{Retired}(year, age) + \\ CW - XR_{Retired}(year, age) \end{pmatrix} + \atop CW_{Early}(year, age) \right] + \atop CW_{NoWasherToWasher}(year) \right\} + \atop CW_{New\ New\ Homes}(year) \quad \textbf{Eq. 9-19}$$

$$CW_{Used}(year) = \left(1 - Prob_{New}(year)\right) * \left\{ \sum \left[0.98 * \begin{pmatrix} CW_{Retired}(year, age) + \\ CW - XR_{Retired}(year, age) \end{pmatrix} \right] + \atop CW_{NoWasherToWasher}(year) \right\} \quad \textbf{Eq. 9-20}$$

where:

CW_{New} (year)	=	The number of new washer purchases in a given year.
$Prob_{New}$ (year)	=	The probability that a purchase is a new washer
$CW_{No\ Washer\ to\ Washer}$ (year)	=	The number of washers purchased by non-owners in a given year.
CW_{Used} (year)	=	The number of used washer purchases in a given year.

In the rest of this report we will describe in more detail how this accounting approach is implemented to forecast clothes washer shipments. [a]

9.3 MODEL

In order to estimate the impact of standards-induced price and features changes it is necessary to have a model which describes consumer decisions and is consistent with historical experience.

In this forecasting effort we took the following approach: First we used the clothes washer consumer analysis to provide the framework for the modeling approach and the probability of purchase model. We then used market discount rates to adjust the relative size of the price and operating savings coefficients for the logit purchase probability model. Finally, we used industry statistics on historical clothes washer shipments to perform the final calibration of the model parameters.

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[a]Note that in Equations 19 and 20, the 98% replacement rate for retired machines was obtained from the Clothes Washer Consumer Analysis.[2]

This procedure for developing the economic decision model is illustrated in the following process flow diagram:

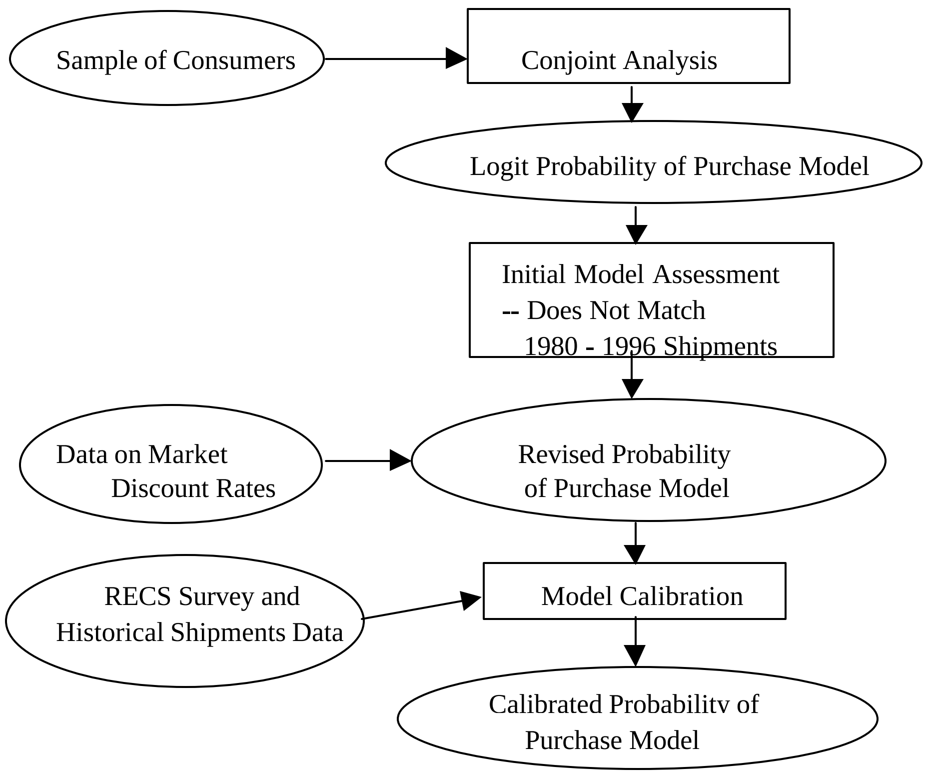

Figure 9.9 Model Development

9.3.1 Logit Probability of Purchase Model

9.3.1.1 Logit Equation

The mathematical building block for the modeling of consumer decision probabilities is the logit probability of purchase model. In this model, the probability of purchase depends on the utility of the clothes washer, 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. These theoretical requirements for the decision probability function can be satisfied by requiring that the probability of purchase function satisfies the following equation:

$$dProb/Prob = dU*(1 - Prob) \quad \textbf{Eq. 9-21}$$

where Prob = decision probability, and dU is the differential change in utility which is a linear function of the clothes washer attribute variables. The factor of (1-Prob) on the right hand side of the equation enforces the condition that the probability of purchase never exceeds 1.

We can solve the above equation for the probability function assuming a particular functional form of the utility in terms of the attribute variables:

$$\mathrm{dU} = \mathbf{b} \cdot \mathrm{d}(\mathrm{Pr}\,ice) + \mathbf{c} \cdot \mathrm{d}(Operating\ Savings) + \mathbf{d} \cdot \mathrm{d}(Feature\,Index) \qquad \textbf{Eq. 9-22}$$

where the differential change in utility is equal to a linear function of differential changes in price, operating savings and features changes. Different versions of the probability of purchase model can use different sets of attributes depending on which economic attributes are assumed to be the primary drivers for the purchase decision. Given the equation for the differential utility, we obtain the following for the probability of purchase:

$$\ln(\mathrm{Prob}/(1-\mathrm{Prob})) = \mathbf{a} + \mathbf{b} \cdot (Price) + \mathbf{c} \cdot (Operating\ Savings) + \mathbf{d} \cdot (Feature\ Index)$$

or **Eq. 9-23**

$$\mathrm{Prob} = 1/(1 + \exp(-(\mathbf{a} + \mathbf{b} \cdot (Price) + \mathbf{c} \cdot (Operating\ Savings) + \mathbf{d} \cdot (Feature\ \ Index))))$$

where **a** is a constant of integration determined by the values of the probability at initial market conditions. This can also be written as:

$$\mathrm{Prob} = \exp(U)/(1 + \exp(U)) \qquad \textbf{Eq. 9-24}$$

where U = **a** + **b**·(Price)+**c**·(Operating Savings)+**d**·(Feature Index) is the utility, and where this equation will change if for different sets of attribute variables. When additional explanatory variables are included in the economic decision model, they are added as additional linear terms in the utility function with their own coefficients. The above equations thus defines the logit probability of purchase model.

Note that the price used in the logit decision model is the NET price of the decision. This means that when we evaluate the decision of a used vs. a new purchase this is less than the price is less than the purchase price of a new machine. Similarly for the decision of a new purchase vs. a repair. For both the repair and the used purchase, we assume that the cost is a fraction of the cost of a new machine. Specifically, we assume that the purchase price of a used machine is 34% of the price of a new clothes washer, and the price of a repair is 24% of the price of a new washer.

9.3.1.2 Utility Coefficients and Elasticity

Once the form of the purchase probability function is defined, the next task is to estimate the coefficients of the model from the available data. In this regard there are four main sources of purchase behavior and ownership data that we utilized: (1) Industry statistics on historical clothes washer shipments,[10, 11, 12] (2) Results from a marketing study of clothes washer consumer preferences, the Clothes Washer Consumer Analysis,[2] (3) AHAM survey results,[1] and (4) EIA/RECS survey results.[13]

For model calibration, we used the conjoint analysis from the Clothes Washer Consumer Analysis was used to verify elements of the model assumptions and set the approximate relative amplitudes of the features and price coefficients. For the next step, we formulated the savings coefficient relative to the price coefficient using intercept survey data on consumer price/savings trade-offs. For the final step, we used historical data to calibrate of the utility coefficient amplitudes, after assuming a given attribute as the primary driver of consumer decisions. Price was selected as the most likely primary driver of consumer purchase decisions, but price/income, income, and interest rate were also examined as possible drivers. We used AHAM and EIA/RECS survey results to set sizes for the initial market segments.

In discussions of price sensitivity of the clothes washer market, much of the technical literature discusses variations in demand in terms of the price elasticity.

For a logit probability of purchase model, purchase price elasticity for a market segment depends on two main parameters: (1) the initial probability of purchase, or likelihood of purchase, of that market segment, and (2) the coefficient for price in the utility function. Specifically:

$$\begin{aligned} elasticity &= (dProb/dPrice)\big/(Prob/Price) = d(\ln(Prob))\big/d(\ln(Price)) \\ &= \mathbf{b} * (1 - Prob) * Price \end{aligned} \quad \textbf{Eq. 9-25}$$

The elasticity therefore decreases with increasing purchase probability, and is proportional to the utility coefficient. Note that elasticity describes changes in purchase behavior for small changes about existing market conditions. For large changes in prices and market conditions, elasticity will not be constant.

The fact that elasticity decreases with increasing purchase probability also helps explain the observation in the long-term sales forecasting literature that elasticities for necessities decrease towards zero as the durable reaches acceptance and market saturation.

In the shipments model, we model price impacts on consumer behavior in terms of the probability function rather than in terms of a simple elasticity value. We use a probability function model so that the impact of large price changes can be properly estimated. When price changes, the purchase probability changes, and so does the elasticity. A full non-linear description of purchase probability variations is a more accurate approach for modeling economic decisions.

9.3.2 Clothes Washer Consumer Analysis

DOE initiated a clothes washer consumer study in order to aid in the description and modeling of consumer preferences and purchase behavior. This study used two approaches to identifying and characterizing consumer preferences: (1) Focus Groups and (2) Conjoint Analysis.

This study is described in detail elsewhere,[2] but we summarize the salient features here.

The focus group study was used to determine what features of clothes washers were of importance to consumers. For the focus group study, the participants indicated which clothes washer features are important to them. The study showed that the ten most important clothes washer features in order of priority are: (1) price, (2) capacity, (3) energy and water costs, (4) load size options, (5) durability, (6) water temperature options, (7) door placement, (8) quiet operation, (9) wash time, and (10) warranty.

In addition to the focus groups, a conjoint analysis was performed to quantify the relative importance of six different features and their impact on purchase probabilities. The conjoint study asked respondents which clothes washers would they consider purchasing today given a range of clothes washer attributes. The prices considered ranged from $400 to $650. Meanwhile the amount of energy and water savings considered ranged from $0 to $50. In addition, features such as door placement, capacity , water temperature options, and load size adjustment were considered in the analysis as binary variables which could be either 0 or 1.

For the shipments model spreadsheet, we included the top four features that may be affected by clothes washer standards. These features, include in order of priority, are: (1) price, (2) energy and water savings, (3) water temperature options, and (4) door placement. (*Note: load size options were rated more important than door placement, but this feature would not be affected by a standard*).

9.3.3 Stated vs. Revealed Preferences

Consumers preferences can be measured or indicated in several possible ways. Stated consumer preferences are those which are obtained through surveys such as the conjoint analysis used in the DOE study. Revealed preferences are those which are demonstrated through actual purchase behavior. The situation in which consumers find themselves when they actually make a clothes washer purchase can be significantly different than the presumed purchase context of a stated preference study. The difference between stated and revealed consumer preferences is noted in textbooks that discuss the application of conjoint analysis:

> Market share estimates obtained from conjoint analysis differ from actual shares due to marketing activities such as advertising and distribution, which affect awareness and availability. Appropriate adjustments are therefore needed to account for the effect of these marketing actions.[14]

Therefore the results of stated preference studies and revealed preference studies can often be significantly different. Especially when considering application to a post-standards situation where the standard affects the availability of lower-efficiency lower-priced models.

Typically a consumer will find himself or herself in a more constrained circumstance during an actual clothes washer purchase. For example, over half of clothes washer purchases are due to the breakdown of an existing clothes washer. Under constrained purchase circumstances consumers will find themselves with fewer choices, and the influence of price, savings, and other clothes washer attributes will diminish.

If one tries to construct a shipments forecast model using stated consumer preferences, it does not fit the historical data. This is due to differences between what consumers say they will buy (stated preferences) and their actual purchase behavior (revealed preferences). This means that while the conjoint study can be used for selected features of the probability of purchase model, most model parameters will need to be calibrated *vis a vis* historical data. This ensures that the probability of purchase model is consistent with revealed rather than stated preferences.

9.3.4 Determination of Decision Sensitivities

Most of the historical variations in clothes washers sales is explained by stock accounting constraints and variations in housing purchases and moves. Over the long term, there is a general increase in the saturation of clothes washers that can be mathematically correlated with any of several economic parameters which may be experiencing a trend over the calibration period. In performing the historical calibration of the consumer decision model, a technical judgement must be made regarding which economic parameter is the primary historical driving force behind consumer decisions.

In this analysis we assumed that appliance price is the primary driver historical trends in consumer decisions based on the importance of price indicated in the Clothes Washer Consumer Analysis and other consumer surveys. In addition, other models with different primary drivers for consumer decisions were examined as sensitivities.

Figure 9.10 Estimated Price vs. Savings Relation for Current Market Conditions

9.3.4.1 Savings/Operating Cost Sensitivity

We estimated the approximate current size of the savings/operating cost sensitivity relative to price using two methods. One method assumes that the current market is in equilibrium, and estimates $\Delta P/\Delta S$ for the current market. The second method analyzes results from a Northwest Energy Efficiency Alliance consumer intercept survey that specifically asks clothes washer shoppers how much of a price increase they would trade off for savings. Both methods give comparable results.

Figure 9.10 illustrates the approximate relationship between price and operating cost savings that is implied by the engineering analysis of the costs of higher efficiency washing machines. Since most purchases are near the baseline model, this data implies a typical market payback time between one and two years, though the precise value in this range cannot be specified with statistical certainty.

Some stake-holders have presented theoretical arguments against the use of market equilibrium analysis to determine the effective market discount rate for consumers. They argue that such an analysis assumes perfect markets (i.e. no lack of knowledge, indivisibility, uncertainty), and that if markets were perfect then standards would not be necessary. This argument neglects the cost of information and its role in market equilibrium. For individuals making a clothes washer purchase it may be relatively expensive and uncertain to discover the actual savings as a function of the diversity of clothes washer choices. Standards perform a collective calculation of optimum cost/benefit trade-offs for improved clothes washer efficiency and therefore drastically reduce the cost of information per clothes washer sale through economies of scale in information production and analysis. Though we may not know the exact cause of high market discount rates for consumer decisions, uncertainty on whether savings will be actually achieved at a personal level provides a plausible explanation for revealed preference market discount rates that are higher than stated preference market discount rates.

Similarly, the intercept interview performed during the Pacific Energy Associates for the Northwest Energy Efficiency Alliance [15] indicated a market discount rate of one to two years for clothes washer shoppers--depending on the details of how the responses are quantitatively interpreted. Given these two indicators, we selected 75% as a market discount rate halfway between a one-year (100% discount) and two-year (50%) payback. The 75% market discount rate corresponds to a price-to-savings ratio of 1.33 for the current market behavior.

The data from the Clothes Washer Consumer Analysis implied a consumer discount rate of 19%, but because of how the choices were structured to allow for a limited set of market discount rate choices, we consider the other methodologies to be more reliable. Specifically, if we divide the average savings on the product choice cards by the average price increment, we obtain a discount rate of 23%. This means that for a set of completely random card selections this will be the average discount rate. In addition, participants in the conjoint survey may have received more information about savings and energy efficiency than average consumers shopping for a clothes washer. In contrast the intercept survey performed by Pacific Energy Associates provided a range of potential trade-offs, and with equal weighting to each of the different choices, and did not provide extra information on energy savings. We therefore consider the intercept survey a more reliable measure of the market discount rate that describes actual consumer behavior in a market with imperfect energy efficiency and savings information.

9.3.4.2 Features Sensitivity

An issue with the higher standards levels (trial standard levels 3-6) is whether the higher efficiency standards will force manufacturers to produce only horizontal axis machines. And if only horizontal axis clothes washers are available, this change in available clothes washer features may impact sales. Among stakeholders, there is no consensus with regards to which standard level might require horizontal axis machines.

Another issue is that the market dynamics of the adoption of new technologies can be extremely complex. Initially, there may be some resistance to a new technology, but as new technologies become more familiar, this market resistance often diminishes. The Bern study of high efficiency clothes washers indicated that consumers can adapt to the technology of front-loading washers, [16] though the implications of the Bern study results for predicting shipments impacts is uncertain.

The conjoint study indicated that there was a rather dramatic change in consumer sensitivity to door placement depending on the level of familiarity with front-loading washing machines, and geographic location. Those consumers who were familiar with front-loading machines have a sensitivity to front loaders that is 30% less than the sensitivity of the entire sample.

In the shipments model, we assumed that if the efficiency of the machine is at the MEF=1.257 level or above is implemented, the dominant machines will be front-loaders. But we also assumed that all consumers would become familiar with front-loading washers and that there would be further acceptance of the new technology. Therefore the size of the top/front loading coefficient in the purchase price model was set at ½ the size of the coefficient for the conjoint sub-sample of those familiar with horizontal axis machines. This value presumes that all consumers will be familiar with horizontal axis machines if they come to dominate the market, and that there will be some adaptation to the new technology, though acceptance will not be complete.

9.3.5 Calibration of Shipments Model

The clothes washer shipments model was calibrated with historical shipments data.

For the calibration of the model that used price as the primary driver of consumer decisions, we fixed the relative size of the price, savings, and front-loading feature coefficients to values determined from evaluation of the Clothes Washer Consumer Analysis, and market discount rates. By finding a market discount rate of 75%, and by estimating the relative size of the front loading elasticity to be about ½ of the sensitivity of the consumers familiar with front loaders, the ratios of the coefficients are fixed as follows:

$$\begin{aligned} \mathbf{c}/\mathbf{b} &= -1.33 \\ \mathbf{d}/\mathbf{b} &= -39.7 \end{aligned} \qquad \textbf{Eq. 9-28}$$

The coefficient b was then adjusted until a best fit of historical data was obtained as measured by the (RMS) deviation between historical shipments and model shipments between 1970 to 1996 inclusive. For the fully calibrated model, the RMS deviation between the model and the industry data on historical shipments is 0.2 million shipments per year.

We also examined the feasibility of explaining historical data with other explanatory parameters as requested by some stakeholders. The results of this analysis are presented in Figure 9.11. The figure shows the optimized historical shipments model predictions utilizing different explanatory economic variables including interest rate, income, price/income, and price. What can be seen in the figure is that while interest rate may have some deficiencies in explaining the historical clothes washer sales, income, price/income, and price can explain the historical sales equally well. It is therefore necessary to use information besides the historical record to determine which of these three economic variables are the most appropriate variable for the shipments forecast.

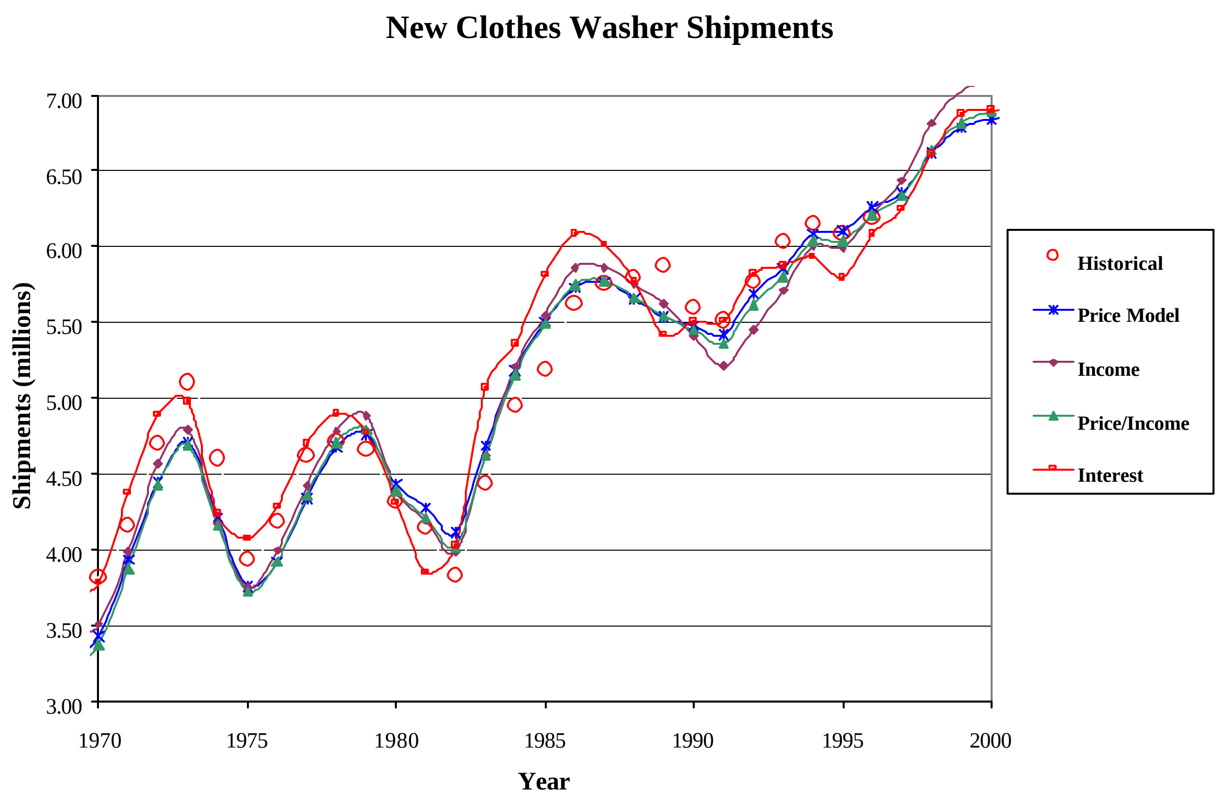

Figure 9.11 Inter-comparison of Models with Different Primary Economic Decision Variables

We use two additional criteria to select the most appropriate primary economic decision variable. The first criteria is whether or not the chosen explanatory variable is consistent with the focus group responses obtained during the Clothes Washer Consumer Analysis, and the second is whether the chosen explanatory variable represents the full range of reasonable forecasted standards impacts.

In the focus group results, participants consistently rated price as the most important clothes washer attribute with capacity being a close second. Therefore, a model which includes only income as an explanatory variable would attach no importance to price and would be inconsistent with the persistent importance of price indicated in the Consumer Analysis.

The next question is whether or not income is a factor in such consumer decision-making. While it is probably true that income was a factor when clothes washer price was relatively large compared to household income, its importance in the recent past when the purchase price of a clothes washer is less than 1% of average annual household income is less clear. The Consumer Analysis found no significant correlation between income and price sensitivity. There is therefore some chance that price is the only primary driver to clothes washer sales. This would be the case if consumers measured the relative benefits of a new clothes washer compared to other consumer purchases they could make, but felt little, if any, income constraints on the purchase. The price-only shipments model uses price relative to other possible purchases by scaling the price relative to the consumer price index for all items.

There is also some chance that price/income is the primary driver to clothes washer sales even though some data supports the price-only model. But if one assumes that price/income is the primary driver one obtains a narrower range of possible standard-induced sales impacts when one does a statistical error analysis. Given the probability that price is (or may be) the primary driver, we therefore conclude that the price-only model and its statistical error analysis more accurately represents the full range of possible impacts and the complete range of uncertainty in the forecasted results.

9.3.6 Range of Shipments Model Forecasts

Given the price-only shipments forecast model we can use statistical analyses to estimate an approximate confidence interval for the calibration of the price sensitivity and consequent uncertainty in the standard-induced shipment impacts. The statistical analysis method that we use is a chi-square analysis. In this analysis, one uses changes in the size of the chi-square metric as a function of the fitted parameter to determine the probability that the actual parameter value is different from the best-fit parameter value.

If we assume that the errors in the data are uncorrelated and normally distributed, and that the minimum root mean square (RMS) deviation between the model and the data is a measure of the standard deviation of the noise in the data, then we can use the chi-square distribution to estimate the size of the confidence interval for the calibration scaling coefficient parameter. The coefficient scaling parameter obtains its minimum value at 0.125. For the 1970-1996 period the number of degrees of freedom is taken as 26, then the chi-square for the 99% confidence interval with 26 degrees of freedom is 55.5. This means that the increase in RMS at the 99% confidence limit is $(45.6/26)^{1/2}$ = 1.3 times the minimum RMS. For the 1970-1996 fit, the RMS deviation increases to 1.3 times its minimum value at approximately 0.25, and it remains below this value for a coefficient scaling parameter of 0. This implies that the 99% confidence interval for the coefficient scaling parameter in the price-only model ranges from 0 to approximately 0.25. The uncertainty interval is probably slightly larger than this because auto-correlations in the random variations would decrease the degrees of freedom in the chi-square analysis. We therefore round up slightly to 0.30 to represent the likely upper range.

To represent the range of possible coefficient scaling parameter values, we chose a coefficient scaling parameter for the price-only model that ranges from 0 to 0.30, with 0.15 as the median value. Given the data available for development of the shipments forecast model at this time, this range should be close to the technically best representation of the possible standards-induced impacts.

Given an uncertain range of forecasted results, the most representative forecast is a matter of judgement. Such judgements depend on the relative importance that one places on different risks and economic factors. For the clothes washer shipments forecast, the high range represents impacts that would be most relevant to those who place much value on the risks of possible sales impacts, while the low end of the range represents impacts that are relevant to those who have confidence in the market's ability to innovate and meet consumer demand. For impartial regulatory applications the median of these two partial views is likely the most representative judgement.

9.4 RESULTS

Once the model is calibrated with historical data, it provides a rather detailed estimate of the possible impacts of standards on purchases, replacement, and repair of clothes washers. In this section we detail the forecasted impacts of the model on different aspects of clothes washer shipments, sales, and retention. Additional charts showing the shipment forecast results for different price elasticities scenarios are presented in Appendix M.

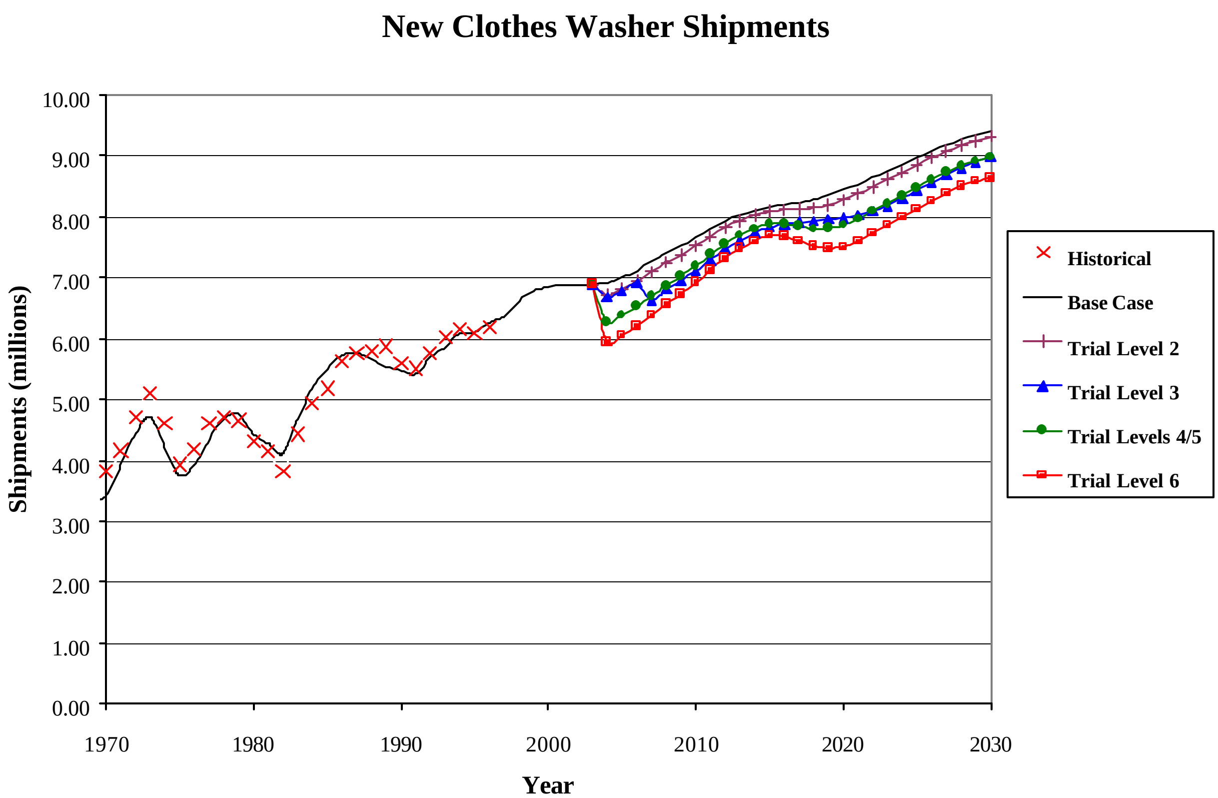

Figure 9.12 Clothes Washer Shipments Forecasts

The results presented in Figure 9.12 represent our best estimate of possible standards impacts on shipments as a function of the trial standard levels. Trial standard level 1 has a less than 1% difference with the base case shipments so it is not illustrated. The illustrated impacts are the ones that would accrue assuming that price is the primary long-term economic driver for changes after the effects of housing, replacements and changes of residence are considered. There is some uncertainty in the forecasted impacts, and the 99% confidence interval for potential impacts ranges from no decrease in sales to a potential decrease in shipments that is approximately twice that shown. These results are those that are implied by the costs given by the engineering analysis which gives the incremental cost for each efficiency level improvement. The forecast assumes no future innovation in decreasing manufacturing costs from current estimates, no progress in improved marketing of clothes washers based on operating savings or increases in consumer income levels. But the model does assume some increasing adaptation by consumers to front-loading machines for those standard levels that my induce changes in the clothes washer configuration (efficiencies above MEF=1.257 are assumed to be front-loading machines).

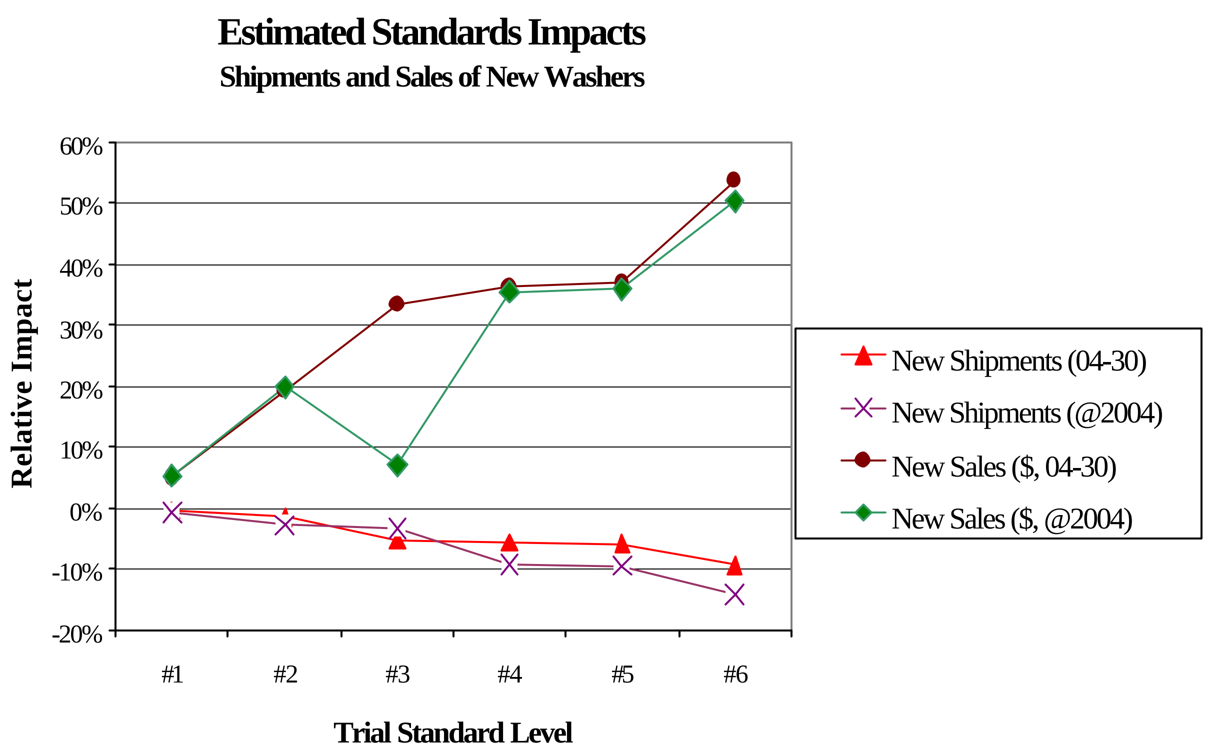

Figure 9.13 Estimated Standards Impacts on New Clothes Washer Shipments and Sales

9.4.1 Sales Impacts of Standards-induced Price Changes

9.4.1.1 New Clothes Washers

Figure 9.13 shows the forecasted clothes washer sales impact of the different proposed standard levels. As shown in the figure, sales and shipment impacts of the trial standard levels 1 and 2 are within 3% of base case. Larger sales impacts are forecast for standard levels above trail standard level 2. For the negotiated agreement (trial standard level 3), the impacts at 2004 are close to trail standard level 1, while the longer-term forecasts are similar to trial standard levels 4 and 5. For trial standard levels 4 through 6, the volume of new clothes washers shipments is forecast to decrease significantly, while total dollar volume of sales is forecast to increase. Both the impacts at the year of the standard and the average impacts over the forecast period, 2004 to 2030, are illustrated.

The biggest factor that influences the size of the potential standards-induced changes is the actual retail price increase that is induced by the standard. If price increases are large, the shipments volume decreases almost proportional to the price increase, but because the price elasticity is less than one, price increases result in increased gross sales dollar volume. The net financial impact of these opposing effects is examined in more detail in the manufacturing impact analysis.

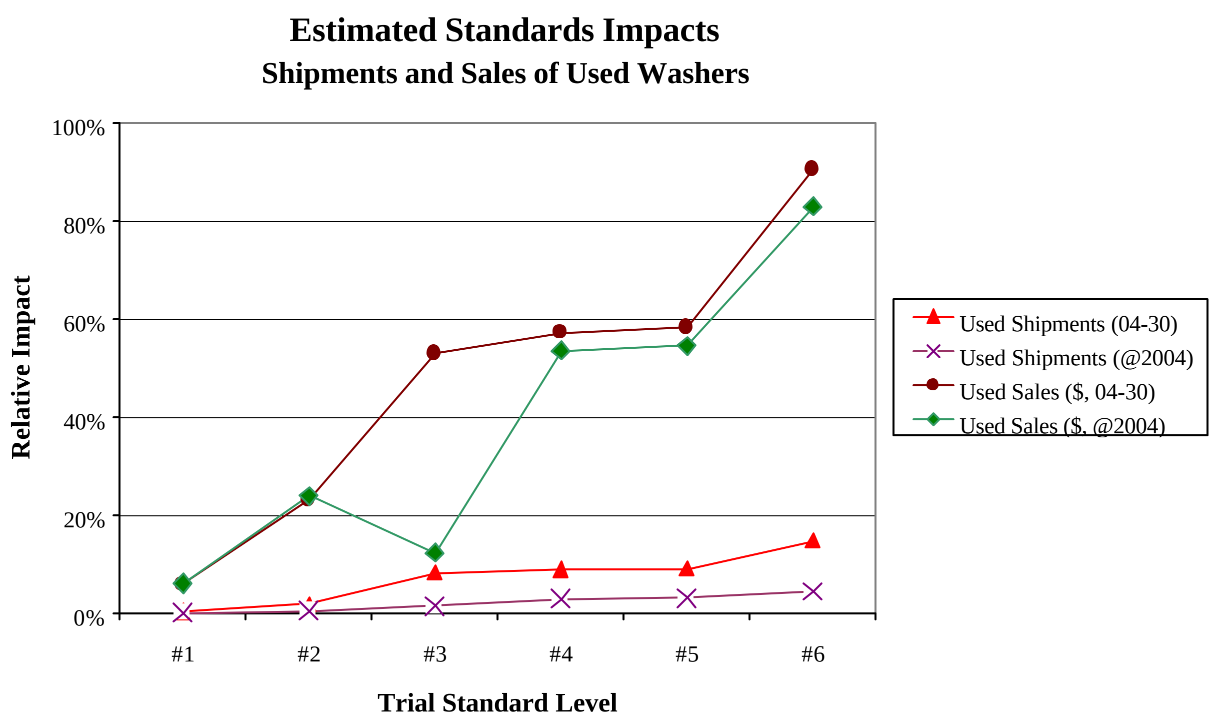

Figure 9.14 Estimated Standards Impacts on Used Clothes Washer Shipments and Sales

Some of the measures that consumers might take to avoid purchase of a new higher-prices clothes washer keep them out of the market for only a relatively short period of time. Therefore there is some recovery from the initial shipments drop that might be seen in the year of the standard.

9.4.1.2 Used Clothes Washers

Figure 9.14 illustrates the potential impacts of standards on the used clothes washer market. The used market will provide one of the most attractive options for consumers having broken clothes washers and who wish to avoid the expense of a new clothes washer. The model estimates that initially, consumers will keep their clothes washers longer, but eventually they will need to be replaced when they breakdown. This means that the long-term increase in the used clothes washer market is larger than the initial increase at the year of the standard.

In estimating the relative impact on used clothes washer sales, we assume that the price of used clothes washers follows the price of new clothes washers and increases proportionally.

9.4.2 Impacts on Mean Age of Washers, Used Market, and Washer Repairs

Figure 9.15 illustrates the estimated impacts on the mean age of clothes washers, the mean clothes washer lifetime, and the total volume of clothes washer repairs. These are average impacts over the standard period of 2004 to 2030. These three different measures of clothes washer retention measure different types of consumer reactions to higher potential clothes washer prices.

The increase in repair rate measures the impact of consumers who perform an extra repair on their clothes washer rather than retire the machine. Such repairs are few compared to the total volume of clothes washer repairs because of the large volume of minor repairs that occur over the lifetime of a washer. According to *Consumer Reports,* about 23% of clothes washers have repairs during the first five years of ownership.[17]

The extended lifetime of clothes washers reflects repairs that consumers might undertake to extend the lifetime of clothes washers. Such extended repairs will have a delayed effect on the average lifetime of a clothes washer, and only a relatively small fraction of machines will receive such extended repairs (some machines may not be repairable, and consumer will also have the choice of purchasing a used washer). An extra repair extends the life of a 14 year old machine by at most six years. At trial standard level 6 less than 10% of machines receive extra repairs that extend the machine life. This implies that the lifetime of washers is increased by at most one half year by the imposition of a standard.

The increase in mean age of a clothes washer illustrates both the impacts of extra repairs and a more vigorous used clothes washer market. When more machines are cycled through the used market, then the proportion of older machines increases slightly, and this results in a slight increase in the average age of machines. Again, it takes several years for used shipments to have a significant impact on the clothes washer age distribution, so the averaged impact over the period is significantly smaller than the peak age increase which occurs several years after implementation of the standard.

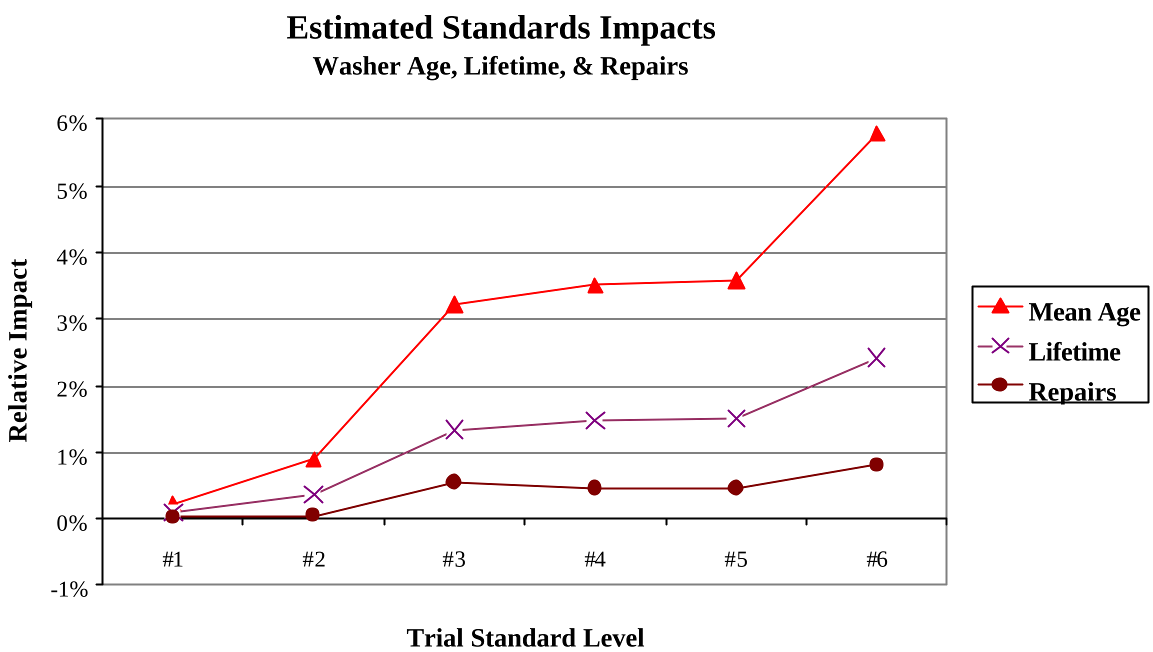

Figure 9.15 Estimated Standards Impacts on Washer Age, Lifetime, and Number of Repairs

9.5 CONCLUSIONS

In order to provide a more detailed picture of potential standards-induced impacts on the clothes washer market, we have formulated an accounting model for clothes washer purchases. The model keeps separate accounts for the new housing, early replacement, breakdown replacement/repair, and non-owner markets. The method also apportions washer purchases to the new and used clothes washer market segments. The method uses a logit probability of purchase model for purchase decisions made by consumers that accounts for the impacts of price, operating cost, and features on shipments.

Model parameters were estimated by using a variety of data sources. The data sources included AHAM data on current market shares for different clothes washer markets, AHAM historical shipments and efficiency data, AHAM engineering data, and results from the Clothes Washer Consumer Analysis.

The shipments model estimates potential standards-induced impacts on new and used clothes washer shipments, gross sales revenue, mean clothes washer ages, lifetimes, and repair rates. Details of the predicted impacts are illustrated in Figures 9.13 through 9.15.

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