CHAPTER 9. SHIPMENTS ANALYSIS

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9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to forecast annual product shipments and presents results for each set of products being considered for this standards rulemaking.

DOE estimated shipments for each product with a shipments model, which is calibrated with historical shipments data. The shipments model considers specific market segments to estimate shipments, the results for which are then aggregated to estimate total product shipments. To estimate the impacts of potential standard levels on product shipments, the shipments model accounts for the combined effects of changes in purchase price, annual operating cost, and household income on the consumer purchase decision.

The shipments model was developed as a part of the NIA spreadsheet that is accessible on the internet (http://www.eere.energy.gov/buildings/appliance_standards/). Appendix 10-A discusses how to access the NIA spreadsheet and provides basic instructions for use.

The rest of this chapter explains the shipments models in more detail. Section 9.2 presents the shipments model methodology for each product; section 9.3 describes the data inputs and the model calibration; section 9.4 discusses impacts on shipments from changes in equipment purchase price, operating cost, and household income; section 9.5 discusses the affected stock; and section 9.6 presents results.

9.2 SHIPMENTS MODEL METHODOLOGY

DOE developed a national stock model for estimating annual shipments for this standards rulemaking. The model considers market segmentation as a distinct input to the shipments forecast. As represented by the following equation, the two primary market segments are new installations and replacements.

$$Ship_p(j) = Rpl_p(j) + NI_p(j)$$

Where:

$Ship_p(j)$ = Total shipments of product p in year j,
$Rpl_p(j)$ = Units of product p retired and replaced in year j, and
$NI_p(j)$ = Number of new installations of product p in year j.

DOE's shipments models take an accounting approach, tracking market shares of each product class, the vintage of units in the existing stock, and expected construction trends. The models estimate shipments due to replacements using sales in previous years and assumptions about the lifetime of the equipment. Therefore, estimated sales due to replacements in a given year are equal to the total stock of the appliance minus the sum of the appliances sold in previous years that still remain in the stock. DOE determined the useful service life of each appliance to estimate how long the appliance is likely to remain in stock. The following equation represents how DOE estimated replacement shipments.

$$Rpl_p(j) = Stock_p(j-1) - \sum_{age=0}^{ageMax}\sum_{j=N}^{j-1} Ship_j \times prob_{Rtr}(age)$$

Where:

$Stock_p(j\text{-}1)$ = Total stock of in-service appliances in year *j-1*,
$prob_{Rtr}(age)$ = Probability that an appliance of a particular *age* will be retired, and
N = Start year for when the model begins its stock accounting (start year is specific to each product based on available historical shipments data).

Stock accounting takes product shipments, a retirement function, and initial in-service product stock as inputs and provides an estimate of the age distribution of in-service product stocks for all years. The age distribution of in-service product stocks is a key input to both the NES and NPV calculations—the operating costs for any year depend on the age distribution of the stock. The dependence of operating cost on the equipment age distribution occurs under a standards case scenario that produces increasing efficiency over time, where older, less efficient units may have higher operating costs, while younger, more-efficient units will have lower operating costs. Furthermore, in the case of an early replacement scenario, retirements due to early replacement will depend on the age of the units that are subject to early replacement.

DOE estimated replacements using product retirement functions that it developed from product lifetimes. For all products, DOE based the retirement function on a Weibull distribution for the product lifetime. The shipments model assumes that no units are retired below a minimum product lifetime and all units are retired before exceeding a maximum product lifetime. The models determine the probability of retirement at a certain age for all products using a Weibull equation:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{ and}$$
$$P(x) = 1 \text{ for } x \le \theta$$

Where:

$P(x)$ = probability that the appliance is still in use at age x;
x = appliance age;
α = scale parameter, which would be the decay length in an exponential distribution;

β =	shape parameter, which determines the way in which the failure rate changes through time; and
θ =	delay parameter, which allows for a delay before any failures occur.

The retirement probability is the difference in the survival function from one year to another.

DOE calculated total in-service stock of equipment by integrating historical shipments data starting from a specific year. The start year depended on the historical data available for the product. As units are added to the in-service stock, some of the older ones retire and exit the stock. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of in-service stocks. For new units, the equation is:

$$\boldsymbol{Stock(j, age} = 1\boldsymbol{)} = \boldsymbol{Ship(j} - 1\boldsymbol{)}$$

Where:

Stock(j, age) =	The population of in-service units of a particular age,
j =	Year for which the in-service stock is being estimated, and
Ship (j) =	Number of units purchased in year *j*.

The above equation states that the number of one-year-old units is simply equal to the number of new units purchased the previous year. The following equation describes the accounting of the existing in-service stock of units:

$$Stock(j+1, age+1) = Stock(j, age) \times \left[1 - prob_{Rtr}(age)\right]$$

In the above equation, as the year is incremented from j to $j+1$, the age is also incremented from *age* to *age+1*. With time, a fraction of the in-service stock is removed, and that fraction is determined by a retirement probability function, $prob_{Rtr}(age)$, which is described in section 9.3. Most replacements are made when equipment wears out and fails. Over time, some of the units will be retired and removed from the stock, thus triggering the shipment of a new unit. Because the products considered in this rulemaking are common appliances that have been used by U.S. consumers for a long time, replacements constitute the majority of shipments.

9.3 DATA INPUTS AND MODEL CALIBRATION

The sections below describe the data inputs and market segments considered for each product.

9.3.1 Historical Shipments

DOE used data on historical shipments (i.e., domestic shipments and imports) to calibrate its shipments model for microwave ovens. DOE's sources for historical shipments data were: (1)

AHAM *Factbooks* for the years 2000[1], 2003[2], 2005[3], 2009[4] covering the period 1989−2009 and (2) *Appliance Magazine*[5] for the period 1981−1988.[a] Table 9.3.1 summarizes the historical microwave oven shipments data.

Table 9.3.1 Microwave Ovens: Historical Shipments, Domestic plus Imports

Year	Shipments (millions)	Year	Shipments (millions)
1980	3.41	1995	8.16
1981	4.18	1996	8.77
1982	3.85	1997	9.14
1983	5.60	1998	10.37
1984	8.63	1999	11.42
1985	10.28	2000	12.64
1986	11.76	2001	13.45
1987	11.91	2002	13.31
1988	10.38	2003	14.27
1989	9.78	2004	15.53
1990	7.69	2005	13.86
1991	6.62	2006	13.69
1992	7.19	2007	11.85
1993	7.24	2008	11.34
1994	8.57	2009	9.63

Source: 1989–2009: AHAM *Fact Books*, 2000, 2003, 2005, 2009; 1981–1988: Appliance Magazine, "Statistical Review," 2009.

9.3.2 Markets and Model Calibration

The market for microwave ovens is primarily comprised of replacement units for equipment that has been retired from service, and units for new housing. Total microwave oven shipments are represented by the following equation:

$$Ship_{MWO}(j) = Rpl_{MWO}(j) + NI_{MWO}(j)$$

Where:

$Ship_{MWO}(j)$ = Total shipments of microwave ovens in year *j*,
$Rpl_{MWO}(j)$ = Replacement shipments in year *j*,
$NI_{MWO}(j)$ = Shipments to new households in year *j*, and

The sections below discuss these markets in further detail.

[a] Shipments estimates from *Appliance Magazine* included exports. Thus, DOE reduced total shipments by 12.3 percent (the average percentage of exports for the years 1989–1993 based on the five-year average difference between the AHAM *Fact Book* 2000 and *Appliance Magazine*) to estimate total domestic shipments plus imports.

New Construction. DOE estimated new construction shipments using two inputs: new housing forecasts and market saturation data. New housing includes newly constructed single- and multi-family units, referred to as "new housing completions," and mobile home placements. For new housing completions and mobile home placements, DOE used actual data through 2005, and adopted the projections from the DOE Energy Information Administration (EIA)'s *Annual Energy Outlook 2010* (*AEO2010*) for the period 2006–2035.[6]

Table 9.3.2 presents historical market saturations of microwave ovens based on various sources, including AHAM's 2009 *Fact Book*,[4] *Appliance Magazine*,[5] NFO World Group,[7] and EIA's RECS for the years 1993,[8] 1997,[9] 2001,[10] 2005.[11] The table presents market saturations for the overall housing stock, new households only, and households with two or more microwave ovens.

Because the forecast of shipments for the new housing market depends on the saturation of microwave ovens in new housing, DOE focused its attention on the market saturations for new housing as well as the saturations of housing with multiple microwave ovens. According to RECS, microwave oven saturation in new housing for 1993, 1997, 2001, and 2005 was 92 percent, 87.5 percent, 93.3 percent, and 90.3 percent, respectively. According to NFO, households with more than one microwave oven represented 3.7 percent, 4.9 percent, and 4.1 percent of the housing market for the years 1990, 1996, and 2001, respectively. RECS did not provide data about number of microwave ovens in its 2005 survey.[b] Therefore, DOE incremented the saturation levels for new housing estimated by RECS by the amounts provided by NFO to estimate the new housing saturations. As a result, DOE determined the effective saturation of microwave ovens in new housing to be 95.7 percent, 92.4 percent, 97.4 percent, and 94.6 percent for 1993, 1997, 2001, and 2005, respectively. Because 2005 is the most recent year for which data are available, DOE decided to freeze the saturation at 94.6 percent to estimate the shipments to new construction for future years.

[b] RECS did not provide data about numbers of microwave ovens per household in its 2005 survey.

Table 9.3.2 Microwave Ovens: Historical Market Saturations

Year	Overall Household				New Households	Households with ≥ 2 ovens
	AHAM*	Appl**	NFO***	RECS†	RECS†	NFO***
1978		7.2%				
1982	25.6%					
1983		33.3%				
1987		65.9%				
1990	82.7%		81.1%			3.9%
1991		85.2%				
1992		84.5%				
1993		85.5%		84.1%	92.0%	
1994		88.8%				
1995		88.9%				
1996		90.6%	88.7%			4.9%
1997		91.0%		83.0%	87.5%	
1998		91.3%				
1999		93.1%				
2000		95.6%				
2001	90.7%	95.7%	91.8%	86.1%	93.3%	4.1%
2002		95.0%				
2003		95.0%				
2004		95.5%				
2005	89.3%			87.9%	90.3%	

* **Source:** AHAM, *Fact Book,* 2005; ** **Source:** Appliance Magazine, "The Saturation Picture," September issues; *** **Source:** NFO World Group, 2001; † **Source:** DOE-EIA, RECS, 1993, 1997, 2001, and 2005.

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. DOE estimated a stock of microwave ovens by vintage by integrating historical shipments starting from the year 1980. Over time, some units will be retired and removed from the stock, thereby triggering the shipment of a replacement unit. Depending on the vintage, a certain percentage of each type of unit will fail and need to be replaced. To determine when a microwave oven fails, DOE used a product survival function based on a lifetime distribution with an average value of nine years, and minimum and maximum values of seven years and 10 years, respectively. For a more complete discussion of microwave lifetimes, refer to section 8.2.2.5 of Chapter 8. Figure 9.3.1 shows the survival and retirement function that DOE used to estimate replacement shipments.

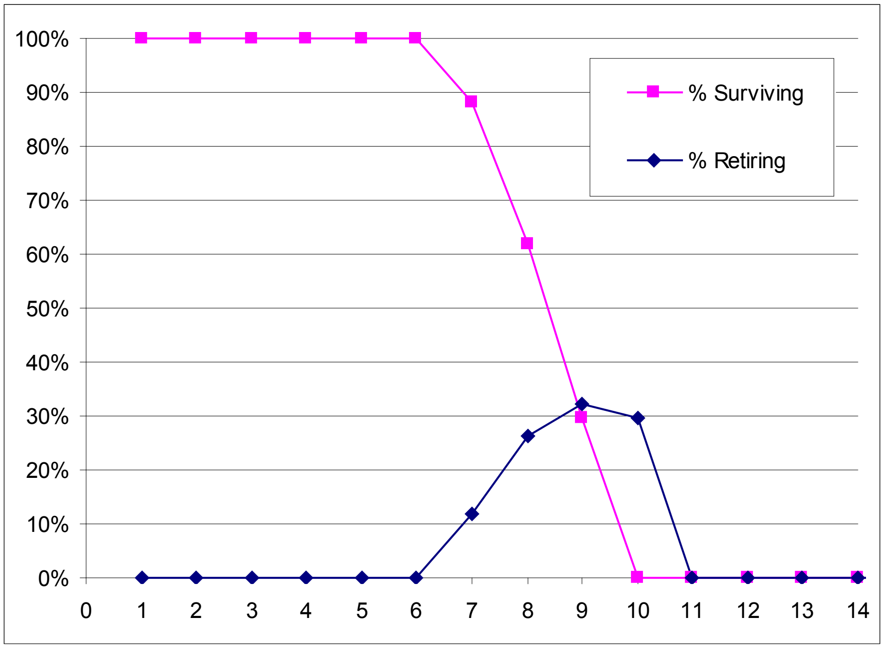

Figure 9.3.1 Microwave Ovens: Survival and Retirement Functions

9.3.3 Base Case Shipments

Figure 9.3.2 shows the forecasted shipments in the base case (i.e., the case without new energy efficiency standards) and the historical shipments DOE used to calibrate the forecast.

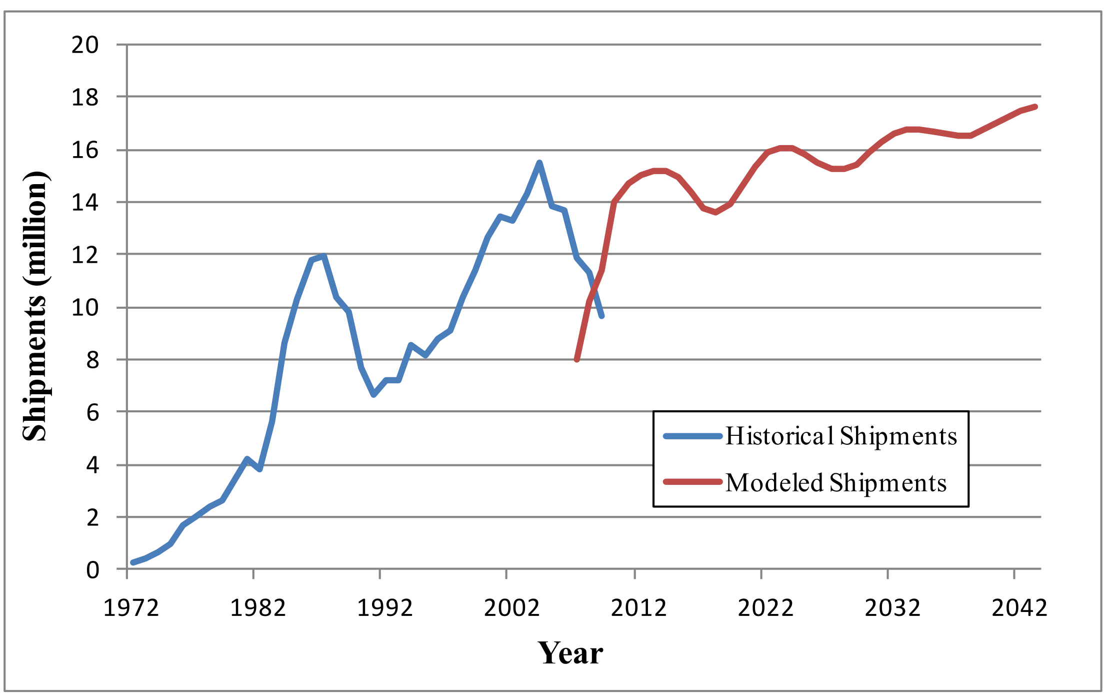

Figure 9.3.2 Microwave Ovens: Historical and Base Case Shipments Forecast

Figure 9.3.3 presents forecasted base case microwave oven shipments disaggregated into shipments due to retirements and shipments to new housing. Note that replacement shipments comprised 85–92 percent of total microwave oven shipments over the period 2006–2035. The percentage of total shipments represented by replacements is high because the microwave oven market is fairly mature.

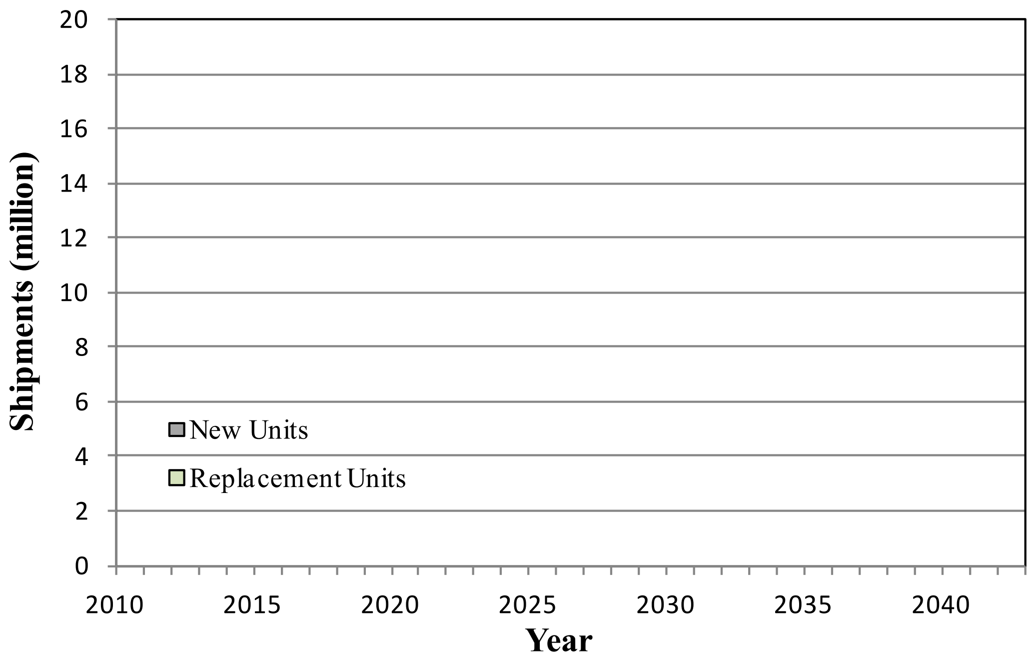

Figure 9.3.3 Microwave Ovens: Disaggregated Base Case Shipments Forecast

9.4 IMPACT OF PURCHASE PRICE INCREASE ON SHIPMENTS

Economic theory suggests that, all else being equal, an increase in the price of a good would lead to a decrease in demand for it. Because DOE projects that appliance standards often result in an increase in the price of the product, DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the effects on product shipments from increases in product price. DOE also considered the decreases in operating costs from higher energy efficiency and changes over time in household income.

In the literature, DOE found only a few studies of appliance markets that are relevant to this rulemaking analysis and identified no studies that use time-series data of equipment price and shipments data after 1980. The information that can be summarized from the literature suggests that the demand for appliances is price inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that consumers use relatively high implicit discount rates[c] when comparing appliance prices and appliance operating costs.

DOE found insufficient data on product purchase price and operating cost to perform a thorough analysis of dynamic changes in the appliance market. Rather, it used purchase price and efficiency data specific to residential refrigerators, clothes washers, and room air conditioners over the period 1980–2002 to evaluate broad market trends and conduct simple regression analyses. These data indicate that there has been a rise in appliance shipments and a decline in appliance purchase price and operating costs over the time period. Household income has also risen during this time. To simplify the analysis, DOE combined the available economic information into one variable, termed the *relative price*, and used this variable in an analysis of market trends, as well as to conduct a regression analysis. The *relative price* is defined with the following expression:

$$\boldsymbol{RP = \frac{TP}{Income} = \frac{PP + PVOC}{Income}}$$

Where:

RP =	Relative price,
TP =	Total price,
Income =	Household income,
PP =	Appliance purchase price, and
PVOC =	Present value of operating cost.

In the above equation, DOE used an implicit discount rate of 37 percent to determine the present value of operating costs.

DOE's analysis of market trends suggests that the *relative price* elasticity of demand for the three appliances is relatively inelastic (i.e., under 1.0). DOE's regression analysis suggests that the *relative price* elasticity of demand, averaged over the three appliances, is -0.34. For example, a *relative price* increase of 10 percent results in a shipments decrease of 3.4 percent. Note that, because the *relative price* elasticity incorporates the impacts from three effects (i.e., purchase price, operating cost, and household income), the impact from any single effect is mitigated by changes from the other two effects.

The *relative price* elasticity of -0.34 is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using simple statistical analysis. More important, the measure is based on an assumption that economic variables, including purchase price, operating costs, and household income, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and

[c] A high implicit discount rate with regard to operating costs means that consumers do not put much economic value on the operating cost savings realized from more-efficient appliances. In other words, consumers are much more concerned with higher purchase prices.

consumer preferences may have occurred during this period, but DOE did not account for them in this analysis. Despite these uncertainties, DOE believes that its estimate of the relative price elasticity of demand provides a reasonable assessment of the impact that purchase price, operating cost, and household income have on product shipments.

Because DOE's forecasts of shipments and national impacts due to standards are over a 30-year time period, it needed to consider how the *relative price* elasticity is affected once a new standard takes effect. DOE considered the *relative price* elasticity provided above to be a short-run value. It was unable to identify sources specific to household durable goods, such as appliances, to indicate how short-run and long-run price elasticities differ. Therefore, to estimate how the *relative price* elasticity changes over time, DOE relied on a study pertaining to automobiles.[12, 13] This study shows that the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the purchase price change, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change. Table 9.4.1 shows the relative change in the price elasticity of demand for automobiles over time. As shown in the table, DOE developed a time series of *relative price* elasticities for home appliances based on the relative change in the automobile price elasticity of demand. For years not shown in the table below, DOE performed a linear interpolation to obtain the *relative price* elasticity.

Table 9.4.1 Change in Relative Price Elasticity following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

Based on the following equation, DOE estimated standards case shipments by incorporating the impact of the *relative price* into the base case shipments forecast. Note that in the equation below, the *relative price* and the *relative price* elasticity are functions of the year because both change with time.

$$Ship_{STD\_p}(j) = \left(Rpl_{BASE\_p}(j) + NI_{BASE\_p}(j) + M_{BASE\_p}(j)\right) \times \left(1 - e_{RP}(j) \times \Delta RP(j)\right)$$

Where:

$Ship_{STD\_p}(j)$ = Total shipments under the standards case of product *p* in year *j*,
$Rpl_{BASE\_p}(j)$ = Units of product *p* under the base case retired and replaced in year *j*,
$NI_{BASE\_p}(j)$ = Number of new home installations under the base case of product *p* in year *j*,
$M_{BASE\_p}(j)$ = First time owners market M of product *p* in year *j* under the base case
$e_{RP}(j)$= *Relative price* elasticity in year *j* (equals -0.34 for year 1), and
$\Delta RP(j)$= Change in *relative price* due to a standard level in year *j*.

9.5 AFFECTED STOCK

The affected stock is the in-service stock of the appliance or product that is affected by a standard level. In addition to the forecast of product shipments under both the base case and the standards case, the affected stock (which represents the difference in the appliance stock for the base case and the standards case) is a key output of DOE's shipments models. The affected stock quantifies the impact that new product shipments have on the appliance stock due to a standard level. Therefore, the affected stock consists of those in-service units that are purchased in or after the year the standard has taken effect, as described by the following equation:

$$Aff\ Stock_p(j) = Ship_p(j) + \sum_{age=1}^{j-Std\_yr} Stock_p(age)$$

Where:

$Aff\ Stock_p(j)$ =	Affected stock of units of product p of all vintages that are operational in year j,
$Ship_p(j)$ =	Shipments of product p in year j,
$Stock_p(j)$ =	Stock of units of product p of all vintages that are operational in year j,
age =	Age of the units (years), and
Std_yr =	Effective date of the standard.

As noted in the above equation, to calculate the affected stock, DOE must define the effective date of the standard. For the NES and NPV results presented in chapter 10, DOE assumed that new energy efficiency standards will become effective in 2014. Thus, all appliances purchased starting in 2014 are affected by the standard level.

9.6 SHIPMENTS FORECAST BY TRIAL STANDARD LEVEL

This section compares the base case shipments forecast with the forecast for the maximum trial standard level (TSL) that DOE considered for microwave oven standby power. As will be described in Chapter 10, the TSLs are comprised of specific candidate standard levels (CSL).

Figure 9.6.1 shows the shipments impacts over the period 2014–2043 caused by the maximum TSL considered for microwave oven standby power for both product classes (TSL 4). For all TSLs, shipments are forecasted to decrease—the effects from the increase in product purchase prices offset the effects from decreased operating costs, resulting in a net decrease in shipments. In Figure 9.6.1, the difference between the base case and the TSL shipments forecast depicts the annual shipments reduction caused by the TSL. The other TSLs have a smaller effect on shipments than does TSL 4.

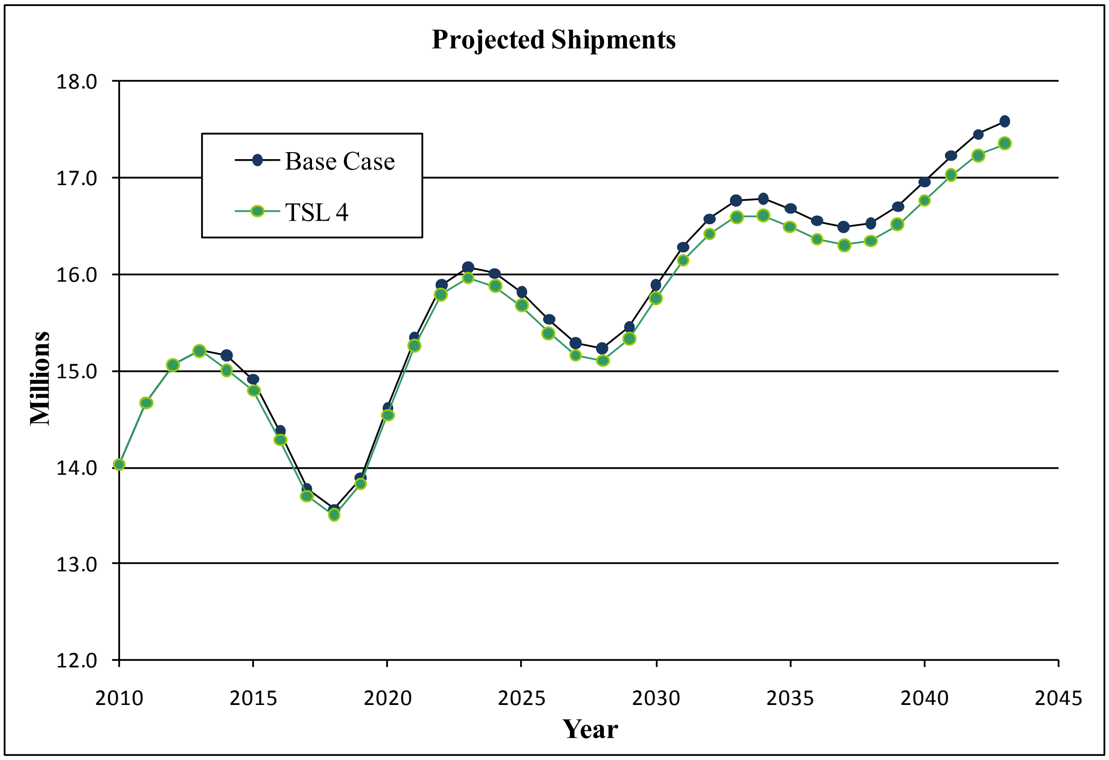

Figure 9.6.1 Base Case and TSL 4 Shipments Forecasts

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