Measuring the Impacts of Australia's Standards & Labeling Program from 1993-2009

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Abstract

As a part of larger efforts to address climate change and curb greenhouse gas emissions, Australia first put categorical energy efficiency labels on residential appliances in the mid-1980s. The first Minimum Energy Performance Standards (MEPS) for refrigerators were later implemented in 1999 and updated in 2005 to align with U.S. levels in 2001, considered to be the world's strictest domestic appliance standards at the time. Considered together, these actions set Australia apart as having one of the most aggressive appliance efficiency programs in the world. For these reasons, Australia is a potentially fruitful case study for understanding the dynamics of energy efficiency standards and labeling program impacts on appliance markets. Fortunately, in the Australian case, market data allows for empirical determination of these questions. This paper analyzes Australian refrigerator efficiency data covering the years 1993-2009. Sales data was obtained from GfK Group and includes data in each year for each product class and each efficiency rating category. Statistical regression analysis is used to model market introduction and adoption of high-efficiency refrigerators according to the logistic adoption model formalism, and parameterizes the way in which the Australian program accelerated the adoption of high-efficiency products and phased out others. The results indicate that the introduction of MEPS accelerated the penetration of high-efficiency appliances onto the market. The MEPS revision in 2005, in which Australia adopted the 2001 U.S. refrigerator standards, ultimately allowed high-efficiency appliances to penetrate the market, but its announcement several years prior and its implementation initially resulted in stagnating adoption rates that remained flat. Through this analysis, this paper not only presents a detailed, robust, and quantitative picture of the impacts of energy efficiency standards and labeling in the Australian case, but also demonstrates a methodology for the evaluation of program impacts that could form the basis of an evaluation framework for similar programs in other countries.

I. Introduction

Australia's domestic electricity consumption has been steadily increasing over the past decade[1], and in 2010 their emissions per capita were among the highest of OECD countries[2]. One fifth of the carbon emissions in Australia are directly linked to domestic households' energy consumption,[3] and typically refrigerators are among a household's top energy users, requiring up to700 kwh/year[4]. These high rates of electric consumption in the general population and in domestic appliances, as well as the high rates of greenhouse gas emissions, underscore the importance of energy efficiency in Australian domestic appliances. Australia has ambitious greenhouse gas reduction goals, aiming to unconditionally reduce their emissions by 2020 by 5% with respect to 2000 levels. Contingent upon international cooperation and global agreements to stabilize atmospheric greenhouse gas levels at 450 ppm (parts per million), Australia strives to reduce their emissions by 25% with respect to the 2000 levels.[5] For these reasons, in 1999 Australia's Ministerial Council of Energy agreed to an aggressive new approach to curb carbon emissions resulting from domestic home appliances. In addition to their already-existing labeling program and minimum energy performance standards (MEPS), the council agreed to significantly strengthen the MEPS for Australian and imported products contributing substantially towards national increases in greenhouse gas emissions[6], most notably for refrigerators.

This analysis evaluates the effects that Australia's energy efficiency labels had on domestic refrigerator sales, and more importantly, the improvement in energy efficiency made by the introduction of minimum energy performance standards. This analysis evaluates the market adoption rates of high-efficiency domestic refrigerators under the comparative labeling and MEPS scheme using data from the Australian market as a case study. The objective of the research is to provide a statistically robust mathematical model of adoption rates over time of such a program and to determine the rate of market energy efficiency improvement before and after program implementation. In addition to the development of a market share model of

[1] (Bureau of Resources and Energy Economics, 2012)
[2] (Energy Information Administration)
[3] (Department of Climate Change and Energy Efficiency)
[4] (U.S. Department of Energy, 2012)
[5] (Department of Climate Change and Energy Efficiency)
[6] (National Appliance and Equipment Energy Efficiency Committee, 1999)

adoption rates, this analysis quantifies the energy savings resulting from the implementation of new standards. This analysis was performed as research for Lawrence Berkeley National Laboratory, and is supported by the U.S. Department of Energy's Super Efficient Appliance Deployment Program (SEAD). The SEAD program is focused on facilitating multi-country collaboration on market transformation toward efficient appliances and equipment.

The new energy efficiency standards for refrigerators were introduced uniformly across Australia in 1999 and 2005, and therefore did not provide a control group against which to compare the uptake of energy efficiency appliances on the Australian market. Thus, a mathematical model was created and used to project the cumulative market shares of various energy efficient models of refrigerators from 1993-2009. The model projects the cumulative market shares under three different scenarios, allowing the analysis to isolate the effects of the energy efficiency labels prior to MEPS, the introduction of minimum energy performance standards in 1999, and the revision to the standards in 2005. The first scenario evaluated is the counterfactual to both the 1999 and 2005 MEPS, which is the market share of energy efficient refrigerators that would exist if no MEPS had been introduced in either 1999 or 2005. In this case, the model is used to project the progression of cumulative market shares and adoption rates in the absence of MEPS. The second scenario isolates the effects of the MEPS in 1999 by modeling how the adoption rates would have progressed if the MEPS had not been later revised and strengthened in 2005. The last scenario, which reflects historical reality, models the progression of adoption rates, given that the MEPS were implemented in both 1999 and 2005. Statistical regression analysis is used to model market introduction and uptake of high-efficiency refrigerators according to the logistic adoption model formalism, and thereby parameterizes the way in which the Australian program accelerated adoption of high-efficiency products and phased out others.

This analysis will first address the current literature on the topic of energy efficiency appliances and how such appliances are perceived by consumers and governments who regulate them. Secondly, the analysis will provide an overview of the data and the model formalism used to produce cumulative market shares and adoption rates. In addition to the theory regarding the model development, this section includes information on fitting the data to the model and determining the parameters. This section also discusses the overall analysis of the data by covering the sequence of calculations required in the analysis, such as the estimation of the parameters, the cumulative and individual market shares, the energy efficiency improvement, and the energy savings. Lastly, a sensitivity analysis is discussed with concluding remarks and policy implications. Through this analysis, this paper demonstrates a methodology of the evaluation of program impacts that could form the basis of an international evaluation framework for similar programs in other countries.

History of Refrigerator MEPS and Labeling in Australia

Australia first put categorical energy efficiency labels on residential appliances in the mid-1980s[7]. The MEPS, later introduced to the domestic refrigerator market in October 1999, are meant to accelerate energy efficiency adoption rates for appliances in advance of what market demand would otherwise provide. These MEPS were later revised and strengthened in January 2005 with a much more aggressive approach of international harmonization with the U.S. 2001 minimum energy performance standards, considered at the time to be the "strictest in the world"[8]. As mandated by the Australian legislature, the MEPS allow the Australian government to prohibit manufacturers from selling their products if they do not meet the standards. Considered together, these actions set Australia apart as having one of the most aggressive appliance efficiency programs in the world. The Australian example represents a potentially fruitful case study for insights in the dynamics of how energy efficiency standards and labeling programs impact appliance markets. Fortunately, in the Australian case, a data resource exists that allows for empirical determination of some of these questions. This paper analyzes Australian refrigerator efficiency data over the years 1993-2009.

The Australian MEPS in 1999 was announced three years prior in 1996, and the 2005 MEPS were announced in 2003. The MEPS levels for 1999 and 2005 were determined using different approaches. The 1999 MEPS levels were determined by using a statistical approach in which 1992 market data was used to evaluate the relationship between energy use and adjusted volume of the appliance determined by a model. The original model sought to draw a line below 40% of available models in each of the nine refrigerator classes, however this statistical method was replaced in 2001 with what is referred to as the "international harmonization" approach.

[7] (Holt, Weston, & Foster, 2011)
[8] (Harrington & Holt, 2002)

This new method consists of updating the 2005 MEPS levels to align with American 2001 MEPS levels for refrigerators[9]. American MEPS levels in 2001 were considered to be the most stringent in the world, and by adopting such standards, Australia eliminated trade barriers and set out to achieve ambitious energy efficiency goals. Meeting these goals was a remarkable achievement for Australia; in October of 2000 not a single refrigerator on the market met the proposed MEPS schedule which was intended to begin in 5 years.[10]

In addition to the new MEPS implementation approach, the energy labeling rating algorithm was re-scaled in 2000 for all labeled appliances (and again in 2010 for refrigerators). The original algorithm, relating the Energy Efficiency Rating index (EER) to energy consumption and volume of the appliance, was a linear relationship based on volume that unfairly biased larger appliances. The new algorithm, renamed Star Rating Index (SRI), uses a geometric relation to relate energy consumption to efficiency level, thus removing the volume bias. The old algorithm, producing six efficiency EER levels ranging from 1 through 6, was replaced with an algorithm producing the same range of SRI levels and including half intervals.

Literature Review

Holt and Weston discuss the history of MEPS in Australia and show that this history is unique due to the country's dramatic change in program standards and the rapid progress that was made in decreasing national energy consumption in domestic refrigerators and freezers.[11] Australia first created their codes and standards program in 1992—the first time that the national energy efficiency program included minimum energy performance standards (MEPS). Mandated by Australian legislation and guaranteed to prohibit the sale of any product not meeting the efficiency standards, the MEPS is a tool designed to be used where the market fails in delivering energy efficiency products to consumers in a manner that is sufficiently rapid to meet climate change goals. While the intent of MEPS is to increase energy savings in domestic households, climate change and environmental impact have been, since the beginning, the dominant motivation of MEPS.

[9] (Holt, Weston, & Foster, 2011)
[10] (Harrington & Holt, 2002)
[11] (Holt, Weston, & Foster, 2011)

Holt and Weston's research indicates that energy efficiency improvement progressed very slowly throughout the beginning of the program in the 1990s, including during the period of implementation of the first MEPS in 1999. The reinvigoration of MEPS in the late 1990s consisted of moving from an approach negotiating product efficiency with supplier representatives in Australia to a new "international" approach in which the government harmonized with the standards of international trading partners. In this case, Australia harmonized with the U.S.'s most stringent codes, implemented within the U.S. in July 2001 and in Australia in 2005. The authors argue that Australia essentially reinvigorated the progress of their MEPS program by simply adopting the world's best energy performance standards and labeling already imposed by major international trading partners.

By adopting the world's most stringent energy performance standards, the new Australian program came to consist of comparative labeling combined with MEPS, allowing consumers to choose products when considering purchase and allowing the government to withdraw the right of sellers if their products fail to meet the standards.

The authors argue that Australia's MEPS program shifted from a program focused on determining "fair and reasonable" product regulation to an international focus, defined by accepting the most stringent MEPS in the United States. Their original process of determining "fair and reasonable" product regulation was based on removing a statistically pre-determined number of models from the market, determined in 1999. Regression analysis was used to evaluate the relationship between energy use and models (adjusted volume), and the original computation sought to draw a line below 40% of available models in each of the nine refrigerator classes. The end result of this statistical method saw a much smaller impact on improving the energy efficiency market than the Australian government officials had expected. The delay in implementation is thought to have resulted in a drastic decrease of potential greenhouse gas reductions and energy savings.

For the MEPS revision in 2005, what the authors call a "new and more aggressive" approach was used to reinvigorate the MEPS program. The new approach, referred to as the "international harmonization approach" was also expected to have economic impacts, as it facilitates international trade of appliances and removes trading barriers.

While this research provides the context of the Australian experience with MEPS and the adoption of the most stringent standards in the world, it provides no quantitative metrics with which to accurately measure market changes in domestic residential refrigerator purchases resulting from both the 1999 and 2005 MEPS. While focusing on the MEPS, this analysis also provides little quantitative information on the effect that the labels had before their use was combined with the MEPS.

Harrington and Holt, in collaboration with the Australian Greenhouse Gas Office, evaluate the impacts of Australia's MEPS harmonization with the world's best regulated efficiency standards.[12] In 1999 Australian federal and state governments began harmonizing with what was considered at the time to be the "best regulatory practice" for minimum energy performance standards. This harmonization applied to residential appliances as well as commercial and industrial equipment in Australia, and involved reviewing mandatory MEPS levels from around the world as well as assessing the requirements with common methods and test procedures. Most importantly, this new policy included adopting the most stringent energy performance standard levels in force at the time and implementing them at some future time in Australia. The first major appliances to be tackled with the new "international" approach were refrigerators and freezers. The 2001 MEPS levels in the United States were identified as the strictest standards in the world at the time, and adopted in Australia for implementation in 2005. The Australian government worked together with importers and local manufacturers to finalize and re-engineer the equivalent models for introduction to the Australian market in January 2005. Projections indicate that a 40% decrease in energy consumption from 2000 levels was required prior to 2005 in order to meet the new MEPS standards. More impressively, during the 15 year period between 1980 and 2005 it is estimated that the sales-weighted energy consumption in Australia of new refrigerator-freezers will have decreased by approximately 70%.

While Australia introduced the first mandatory labels for refrigerator-freezers in 1986, mandatory labels were introduced in 1990 for other appliances, including clothes dryers, air conditioners, clothes washers, and dishwashers. It is difficult to isolate the effect that the labels and the 1999 MEPS had, but the labels did not appear to have much effect on accelerating the

[12] (Harrington & Holt, 2002)

market for energy efficient appliances. Australia addresses their challenging and aggressive 2005 goal by adopting the MEPS levels from trading partners such as the United States.

Other countries have MEPS as well, although they are not as strict as the American standards. Japan has a quasi-mandatory energy efficiency program for manufacturers called “Top Runner,” however very little information exists on this program. This program, announced and developed in 1999, identified the most energy efficient models on the Japanese market at the time. Japan then used this level as their sales-weighted target for manufacturers for future revisions of standards. Korea’s MEPS program has been in place since 1996. However, their standards levels since 1999 have been weaker than the U.S. 2001 levels. Minimum energy performance standards also exist in Taiwan, China, and Russia. However, detailed information on these programs are difficult to come by. The MEPS levels in these countries were found to be less stringent than the U.S. 2001 levels. The European Union MEPS levels implemented in 1999 for refrigerators were found to be weaker than the 1999 MEPS levels in Australia. For refrigerator products that are cooled convectively, the E.U. levels in 1999 were comparable to the U.S. 1993 MEPS levels. However, the E.U. levels were weaker than U.S. 1993 MEPS levels for refrigerator products that are frost-free.

Harrington and Holt’s analysis provides a detailed historical account of the Australian incentives for adopting the world’s strictest energy efficiency standards for domestic appliances. However, their analysis provides no quantitative metrics with which to evaluate the changes in the Australian market or the isolated effect of the labels without the MEPS.

Van Buskirk’s analysis of the adoption curves and fitting methods for estimating market efficiency improvement and acceleration provide a strong framework of analysis for evaluating adoption rates of energy efficient technologies in Europe.[13] His initial study provides a set of equations for characterizing the dynamic evolution of product efficiency distributions. Similar to the methods used in my analysis, Van Burskirk also uses the Bass function has a model formalism to emulate the progress made in European domestic refrigerator markets. His methods provide an accurate method of evaluating energy efficiency improvement by projecting potential long-term energy efficiency improvement from relatively short time series data.

[13] (Van Buskirk, 2012)

In contrast to the analysis presented in this paper, Van Buskirk's methods of determining energy efficiency improvement focus on the median market share of appliances, and tracking the years in which that median market share is achieved. Additionally, Van Buskirk's methods are based around measuring the impacts of one MEPS implemented in 1995 in Europe, while the analysis provided in this study of Australian refrigerators focuses on measuring the combined impact of two separate MEPS in Australia in a similar domestic refrigerator market. Because of the complications arising from the effects of two separate MEPS spaced six years apart, my analysis could not use the same metrics of energy improvement as in Van Buskirk's study. The analysis I provide, in which synthetic counterfactuals are created to evaluate the impact of the MEPS in both 1999 and 2005, provides a framework for determining the energy efficiency improvements resulting over time from several MEPS revisions. Both studies evaluate the impact of joint MEPS and labels.

Ruderman et al.'s analysis makes the case for federal policy intervention to accelerate the U.S. market for energy efficiency appliances in a desired direction where simple market demand is not sufficient[14]. The analysis is performed for a wide range of household appliances, including refrigerator-freezers, and uses investments and pay-back periods as the main metric in the analysis. Their findings indicate that threshold behavior, behaviors triggered by a threshold value of savings, is a factor in determining the market for energy efficiency appliances. Additionally, they argue that design changes for appliances are usually the result of manufacturers' profit maximization or efforts to increase reliability, rather than optimizing energy efficiency. The cost of design changes to appliances to incorporate energy saving features constitutes a fraction of the overall costs of production. Because of the complexities in re-engineering appliances, manufacturers will typically wait for another manufacturer to take the lead in introducing a more efficient product, and follow in their steps only if the new product threatens their own market share. Hence, a typical cycle for introducing a new line of products onto the market is approximately 3 years.

Waide et al.'s analysis argues that while the minimum energy efficiency standards (MEES) were voluntary in Western Europe, consumers and the environment would benefit

[14] (Ruderman & Levine, 1987)

greatly from mandatory standards.[15] In studies evaluated by Waide et al., energy consumption in domestic appliances will continue to grow rapidly until the MEES become mandatory. The analysis indicates that the MEES are the most cost-effective method of making deep and rapid cuts in European electricity consumption, and that this method is significantly more cost-effective than labeling, which was voluntary on European appliances for 16 years up until September 1992.

Newell et al.'s study on induced innovation and technological changes to energy-saving appliances tests Hicks' hypothesis that increasing energy prices will result in technological changes that facilitate the diffusion of energy-efficient goods.[16] This model is expanded to allow for the influence of governmental regulations, such as the MEPS being evaluated in Australia. The study was performed with publicly available data in the United States from 1958 to 1993 on heating and cooling appliances, such as central air conditioners and gas water heater models. Their economic model has yielded three important findings. Firstly, the findings suggest that the *rate* of overall innovation was not related to energy prices and regulations, but that the *direction* of innovation was responsive to these factors. The findings also indicated that increasing energy prices affected which technically feasible appliance models were available on the market. This observable effect was particularly strong after product label requirements were introduced. Lastly, and most importantly, the results show that government energy efficiency standards also had significant effect on the market availability of energy efficiency appliances.

Shen and Saijo conducted a hypothetical choice experiment to evaluate the impact that the China Energy Efficiency Label has on consumers' choice of air refrigerators and conditioners.[17] Their results show that consumers are, fortunately, very much aware of the labels, and that their decisions are strongly influenced by their knowledge of the energy efficiency characteristics of the appliances. The study suggests that consumers are likely to respond very positively, and are likely to prefer the products for which manufacturers have provided energy efficiency labels. Additionally, the findings suggest that the consumers have a higher willingness to pay for energy efficient refrigerators than for air conditioners. This preference indicates that in the case of Shanghai, and potentially in other markets for energy efficient appliances, consumers have a

[15] (Waide, Lebot, & Hinnells, 1997)
[16] (Newell, Jaffe, & Stavins, 1999)
[17] (Shen & Saijo, 2009)

greater incentive in paying for energy efficiency appliances when those appliances are ones that they use frequently.

II. Methodology

The Data

This paper analyzes Australian refrigerator energy efficiency data covering the years 1993-2009. Sales data was purchased from a commercial market research company (GfK Group) and the data was cross matched by Energy Efficient Strategies on contract to the Australian government as part of its ongoing monitoring and evaluation program. The data includes sales by model, which are then aggregated into product categories and star rating. While there are currently multiple categories of refrigerators and freezers on the Australian market (called Groups), this analysis focuses on the four categories of refrigerators described as combined refrigerator-freezers, which constitute approximately 80% of the Australian refrigerator market.[18] The star system, indicating the energy efficiency of the appliances, ranges from 1.0 stars to 6.0 stars in half intervals (where 1.0 is the least efficient and 6.0 is the most efficient).

The data, used to evaluate the impact of the 1999 and 2005 MEPS, are separated into 3 time periods delineated by the introduction of new MEPS.

- Period 1: 1993-1999
- Period 2: 2000-2003
- Period 3: 2005-2009

The 1999 MEPS were introduced in the last annual quarter (October) and therefore the pre-1999 MEPS period is considered to be from 1993 through 1999. However, the 2005 MEPS revision occurred in January of that year, so the post-2005 MEPS period includes 2005 and is considered to be 2005 – 2009. The year 2004 was excluded from the model because the data reveals that it is a year of strong transition. The stark difference in market share in 2004 risked throwing off the regression statistics used to determine the parameters of the model, and therefore this period was excluded from the model.

[18] (Energy Efficient Strategies, 2006)

Statistical regression is used on the market share data of each star rating level for each time period to determine the rate of uptake of efficiency improvement. The regression parameters are then used in conjunction with the logistic formalism to develop S-curves representing the cumulative market share across efficiency levels.

The Market Share Model

Individual Market Share Data and Cumulative Market Share

The data includes sales in each year for each product category and each star rating, which ranges from 1 to 6 stars in half star intervals. This data was used to obtain the market share percentage in each year of each efficiency rating. The individual market share percentage for each efficiency level indicates the percentage of the Australian market for residential refrigerators of each efficiency level. For example, if a refrigerator rated 4.0 stars has a market share of 15% in 1993, this means that in 1993 refrigerators with a 4.0 star rating only made up 15% of the total residential refrigerator market in Australia.

For this analysis, the cumulative market share across efficiency levels is used as the principal variable to evaluate the impacts of changes in efficiency over time. This cumulative market share of a specified efficiency level represents the additive value of the market shares of all of the star ratings equal to or greater than that star rating. For example, if the cumulative market share in 1993 for a 3.0-star appliance is 3.4%, then all appliances rated 3.0 or greater constitute a combined market share of 3.4%. The cumulative market share across star efficiency levels appears to be the best metric to evaluate the energy efficiency improvements because energy efficiency technologies that are used in one level are assumed to apply to higher levels as well.[19]

Model Formulism

Bass Diffusion Model

Frank Bass's seminal paper in 1969 laid out the framework for modeling the diffusion of new technologies. The Bass diffusion model, which has long been regarded as one of the most

[19] (Van Buskirk, 2012)

accurate models for forecasting the innovation and diffusion of new technologies, is defined by the following differential equation:

$$\frac{dF(t)_{Bass}}{dt} = \left(p + qF(t)\right)(1 - F(t))$$

Where F(t) is the fraction of the market that has adopted the new product, p is the “innovation coefficient”, q is the “imitation coefficient”, and 1 represents the full market share potential.

The Bass model above parameterizes factors representing both internal influences (e.g. word of mouth) and external (e.g. mass media communication). Internal influences are also referred to as the “imitation coefficient”, referring to the market adoption resulting from consumers who imitate their peers and are influenced by internal factors such as word of mouth. External influences, resulting in “spontaneous” adoption of new technologies, refers to influences that are not time-dependent (such as previous adoption by other consumers), but rather external agents of change, such as marketing and advertising[20]. Innovators are defined as not being influenced by the number of previous buyers in their initial purchase, while the influence on imitators is time-dependent and influenced by the choice of earlier consumers.[21]

The equation above states that the rate of change of the cumulative market share (dF(t)/dt)) is proportional to the full market share (100%) and previous market shares. The factor of proportionality is (p + qF(t)) and can be interpreted as the probability of adoption at time t. This probability consists p and qF(t), where p is the probability of adoption due to external influences. The term qF(t) corresponds to the probability that technologies will be adopted based on previous adopters[22]. The term (1-F(t)) corresponds to the fraction of the market that has yet to adopt the new technology. Additionally, since F(t) corresponds to the cumulative market share, by the definition of derivatives, it follows that individual market share of each efficiency level for each year is dF(t)/dt.

[20] (Elliott, Anderson, Belzer, Cort, Dirks, & Hostick, 2004)
[21] (Bass, 1969)
[22] (Elliott, Anderson, Belzer, Cort, Dirks, & Hostick, 2004)

Once solved analytically, this equation becomes the following:

$$F(t)_{Bass} = \frac{1 - e^{-(p+q)*t}}{1 + \frac{q}{p} * e^{-(p+q)*t}}$$

For a typical Bass diffusion curve the initial condition of the S-curve is F(t=0) = 0, and t_0 is the reference point such that $F(t_0)$ = 0.5. However, the defining differential equation above can also be solved analytically such that the S-curve is not assumed to pass through F(0) = 0. As such, the analytical solution becomes the following[23]:

$$F(t)_{Bass} = \frac{1 - \frac{p}{q} e^{-(p+q)(t-t_0)}}{1 + e^{-(p+q)(t-t_0)}}$$

Logistic Model

The logistic function is a specific case of the Bass diffusion model. As in numerous studies of the diffusion of energy efficient technologies, this analysis is concerned with the value of q, the coefficient of imitation of new technologies, rather than the coefficient of innovation represented by p. Due to the difficulties in estimating p, as well as the purpose of this study to evaluate internal and time-dependent factors in the diffusion of new technologies, p=0 in the equation above. Most importantly, when p is trivial, the equation reduces to the logistic function, which can more easily be converted to a linear function, allowing for a linear regression analysis and estimation of the parameter q and t_0. Additionally, previous studies have shown that the logistic equation is an appropriate formalism for modeling the diffusion of refrigerators.[24] An explanation of how the Bass function simplifies into the logistic function follows below.

When p=0, i.e. the coefficient of innovation is equal to zero, the equation above reduces to the following equation, which is, by definition, the logistic function:

$$F(t) = \frac{1}{1 + e^{-q*(t-t_0)}}$$

- where F(t) indicates the cumulative market share of a specified appliance for a specific year;

[23] (Van Buskirk, 2012)
[24] (McNeil & Letschert, 2010)

- t represents the year of the market share data;
- t_0 is such that $F(t_0) = 0.5$;
- q is the parameter representing the coefficient of imitation.

The general form of the cumulative market share relationship with time follows the logistic function defined above, producing an S-shaped function, called a sigmoid function because of its shape. By definition, the logistic function has a maximum of 1, at which point market saturation is reached. The minimum of the function is 0, at which point the product has no cumulative share of the market.

Analysis of the Data

Linearization

A linearization is performed on the data to estimate the cumulative market share with a function that can be estimated linearly. The goal of estimating the cumulative market share linearly is to perform regression analysis on the function and to estimate the value of the parameter q, the coefficient of imitation.

A plot of the raw, untransformed cumulative market shares is provided in the Appendix in Figure 1. The data used for the remainder of the analysis was linearized, shown below and illustrated in Figure 2.

As seen in the equation above, the logistic equation is defined as follows:

$$F(t) = \frac{1}{1 + e^{-q*t}}$$

The purpose of the linearization is to obtain linear data which is more suitable for linear regression analysis. The steps of the linearization are described as follows:

Let $Z(t) = \frac{F(t)}{1-F(t)}$

Taking the natural log of both sides of the equation results in the following:

$$\ln\big(Z(t)\big) = \ln\big(F(t)\big) - \ln\big(1 - F(t)\big)$$

$$\ln(\mathrm{Z(t)} = \ln(\frac{1}{1+\,e^{-q*t}}) - \ln(\,1 - \,\frac{1}{1+\,e^{-q*t}}\,)$$

$$\ln\big(Z(t)\big) = \,-\ln(e^{-qt})$$

$$\ln\big(Z(t)\big) = q * t$$

By linearizing the data the cumulative market share function is transformed into a linear function on which a regression analysis can be performed. The regression analysis will be used to estimate a value of the parameters q and t_0.

Once the data is rescaled, the data is divided into 3 time periods: pre-1999 MEPS, 2000 to 2003, and post-2005 MEPS. The time periods are defined as follows:

- Period 1: 1993-1999
- Period 2: 2000-2003
- Period 3: 2005-2009

Estimation of Parameters: q and t_0

In order to fit the data, a regression is performed for each year on each of the 3 segments of the data delineated above to determine the slope of the trend line. The slope of the regression, representing the rate of adoption of new appliances, is represented by q. While the regression constant c does not appear as a parameter of the model, it is used to determine the value of t_0, the year at which the cumulate market share is 50% (i.e. the inflection point of the S-curve). Following from the fact that t_0 is such that $F(t_0)$ = 0.5, we get $t_0 = \frac{-c}{q}$.

An illustration of the linearized data sectioned into 3 periods is provided in Figure 3, and the results of the regression are summarized in Table 1. As an example of interpretation, in the case of star efficiency level 2.0, the slope of the market share in time Period 1 is 0.42, while in time Period 2 it is 0.25 and in Period 3 it is 5.65. These values indicate that the market share for appliances that have a rating of 2.0 or greater is growing fastest in Period 3 and slowest in Period 2.

Once the values of q have been determined for each time period and each efficiency level, the logistic transformation is used to model the anticipated cumulative market share of each efficiency level in order to develop a synthetic counterfactual of what the market shares would be if there had been no MEPS in 1999 or 2005.

Most importantly, this model assumes that each new MEPS implementation (occurring in both 1999 and 2005) triggers a change in the rate of change of the linearized market shares, thus changing the value q. Figure 5 illustrates the S-curves for all of the efficiency levels, as well as the data points that were used to estimate the parameters. This figure provides a comparison of the model projection and actual data points, and illustrates the goodness of fit of the model.

Market Share Projections

Cumulative Market Shares

This model produces 'S-curves', illustrating the changing cumulative market share value over time of each efficiency level. The S-curves are used to model three different historical scenarios. A description the three scenarios follows:

- **Scenario 1**: No MEPS were implemented in either 1999 or 2005. This scenario models the cumulative market share if no MEPS had been implemented; this is the counterfactual to both of the MEPS in 1999 and 2005. (The q value remains constant for each year in this scenario).
- **Scenario 2**: MEPS were implemented in 1999, but not in 2005. This scenario models the effect that the MEPS in 1999 had on the cumulative market share and estimates what the cumulative market shares would have been after 1999 assuming that no additional MEPS were implemented. (In this case, the value of q for each year is the same in Period 2 and Period 3, but different in Period 1.) This scenario could be considered a second counterfactual—the counterfactual to the MEPS in 2005.
- **Scenario 3**: MEPS were implemented in both 1999 and 2005. This scenario models the effect that the MEPS had on the cumulative market shares assuming that both the MEPS in 1999 and 2005 had been implemented. This scenario models the actual historical reality of the MEPS implementations. (In this case the value of q is different in each time period for each year.)

As mentioned above, a change in labeling policy such as the ones introduced in 1999 and 2005 causes the value of q to change. A summary of the scenarios and the values of q that are used is provided below. It is important to note that while the assumption is that the MEPS changes the value of q, the remaining regression coefficients change as well. The regression statistics are summarized in Table 1 of the Appendix.

Scenario Name	Description	Value of q parameter	Number of Values of q
Scenario 1	No MEPS	Constant q	1
Scenario 2	MEPS in 1999	Value of q changes in 1999	2
Scenario 3	MEPS in 1999 and 2005	Value of q changes in 1999 and 2005	3

Scenario Summary and Changes in Parameter Values

Individual (Non-Cumulative) Market Shares

As noted in the description of the model formulism, the individual market share corresponds to the derivative of the cumulative market share with respect to time. Therefore, the S-curve model producing cumulative market shares can also be used to determine individual market shares for each efficiency level. The individual market shares for each efficiency level and each year (MS_{SRI}), can be expressed in terms of the cumulative market share (CMS_{SRI}) as follows:

$$MS_{SRI} = \frac{\mathrm{dF(t)}}{\mathrm{dt}} = CMS_{SRI+0.5} - CMS_{SRI}$$

For example, the individual market share of 2.0 star appliances in 1993 can be found by subtracting the cumulative market share of 2.5 star appliances from the cumulative market share of 2.0 star appliances. The individual market shares were calculated in this way and the results are provided in Figures 8 - 12. Figure 8 depicts the individual market shares over time for all appliances in scenario 1. Figure 9 illustrates the markets share progression of the low-efficiency appliances (1.0 star – 3.0 stars) in scenario 2 whereas Figure 9 illustrates the progression for high-efficiency appliances (3.5 stars – 6.0 stars). Figures 11 and 12 illustrate similar figures with the same breakdown for scenario 3, and also provide the actual data points provided by GfK to see the goodness of fit of the model.

Energy Efficiency Improvement

The ultimate goal of the cumulative market share projection is to evaluate the energy efficiency improvement and energy savings resulting from the 1999 and 2005 MEPS. The energy efficiency improvement calculation is based on the comparative energy consumption (CEC), which corresponds to the energy consumption appearing on the energy label and that is available to consumers. This energy consumption is measured in KWh/year and is used with the market share data to obtain a weighted average of the yearly energy consumption by energy star rating. The two steps in this calculation are: 1) Calculating the CEC for each star level for each year; 2) calculating the weighted average of the projected CEC by using the market share projections for each efficiency level for each star level. The equations below detail the calculation involved in the two steps mentioned above.

Comparative Energy Consumption

The refrigerator star rating algorithm[25] is:

$$SRI = 1 + \left[\frac{ln\frac{CEC}{BEC}}{\ln(1 - ERF)}\right]$$

In the equation above, the terms are defined as follows:

SRI is Star Rating Index (star efficiency level)
CEC is Comparative Energy Consumption (energy that appears on the energy label)
BEC is Base Energy Consumption (this also corresponds to the 1.0 SRI level).
ERF is the Energy Reduction Factor (this is the reduction factor of CEC for each additional star).

The BEC is defined as follows:

$$BEC = Cf + Cv * (Adjusted\ Volume)^{0.67}$$

Where Cf is the fixed allowance factor, and measured in kWh/year,
Cv is the variable allowance factor, measured in kWh/year/L,

[25] (E3, 2010)

And ERF = 0.23 for refrigerators.

The data from GfK provided the SRI, the BEC, and ERF. As follows from the equation above, the CEC for each year and each efficiency level can be determined by rearranging the above equation in the following manner:

$$CEC = e^{SRI*\ln(1-ERF)+\ln BEC}$$

Weighted Average Annual Consumption

Obtained with the equations listed above, the yearly average CEC is then multiplied by the total individual market shares of each efficiency level for each year to obtain the weighted average yearly energy consumption for each level. The individual market share was determined from the model and is defined in above. The equation for the yearly average CEC is as follows:

$$Yearly\ Average\ CEC_{SRI} = \sum (CEC_{SRI}) * (MS_{SRI})$$

Where:

- CEC_{SRI} is the yearly comparative energy consumption for each star efficiency level,
- MS_{SRI} is the yearly percentage market share for each star efficiency level.

The formulas described above to determine the yearly CEC for each efficiency level were then used in conjunction with the projected market share model to produce a projected counterfactual of consumed energy. Figure 13 illustrates these counterfactuals and shows the energy consumption over time, illustrating the energy efficiency improvement.

Energy Savings

The energy savings are determined by calculating the difference of the weighted average energy consumption between the various scenarios. The difference is calculated as follows:

$$Energy\ Savings\ from\ 1999\ MEPS = (Weighted\ Average\ CEC_1) - (Weighted\ Average\ CEC_2)$$

$$Energy\ Savings\ from\ 1999\ and\ 2005\ MEPS = (Weighted\ Average\ CEC_1) - (Weighted\ Average\ CEC_3)$$

Where CEC_i is the yearly weighted average of energy consumption in scenario i.

In the equations above, the weighted average CEC are calculated from the S-curves produced by the model. The energy savings can be seen in Figures 14 and 16.

III. Interpretation of Results

Market Share Projections

Cumulative Market Shares

Figures 5 – 7 illustrate the cumulative market share in scenarios 1, 2, and 3, respectively. The dotted lines in each of the figures represent the counterfactual cumulative market share, the solid lines represent the model fit of the scenario, and the points are the actual market share data points provided by GfK.

Scenario 1: No MEPS in 1999 or 2005

Scenario 1, shown in Figure 5, illustrates the expected progression of cumulative market shares assuming that no MEPS are implemented in either 1999 or 2005. Because the MEPS are not implemented in this scenario, the scenario isolates the influence of labels on the progression of the cumulative market shares. As seen in the figure, higher efficiency appliances (3.5 stars – 6.0 stars) are not included because the model predicts that with no MEPS they will not be introduced onto the market. As such, the model predicts that throughout time periods 2 and 3, the cumulative market share of the low efficiency appliances increases significantly and dominate the market.

The 1999 MEPS was announced 3 years prior to the implementation, in 1996. Figure 5 indicates that the time where the MEPS were announced in 1996 corresponds to the inflection point of the data, indicating that this is when the real uptake in adoption occurred. The following years leading up to 1999 are what would be considered as transition years, illustrating the effects of an “anticipation effect” by the manufacturers. This is the point at which the manufacturers rushed to re-engineer their appliances to meet the new standards.

The sudden uptick in 1996, the date at which the 1999 MEPS were announced, indicates that the MEPS announcement had a much stronger influence on the cumulative market share than the labels did.

Scenario 1, in which there was no MEPS in 1999 or 2005, illustrates that in 1993 the only efficiency levels that have penetrated the market are the lower efficiency levels, such as the 1.5, 2.0, 2.5, and 3.0 star levels. Higher efficiency levels did not constitute any percentage of the market in 1993, and as the model illustrates, they only entered the market after the first MEPS in 1999. However, the absence of solid lines for efficiency levels 3.5 through 6.0 implies that the higher efficiency levels would not been introduced to the Australian market if it were not for the MEPS in 1999.

Scenario 2: MEPS in 1999

Figure 6, illustrating scenario 2, illustrates the impact of Australia's MEPS implementation in 1999. As shown in time period 2, the projected cumulative market share for the two lowest efficiency levels, 1.5 and 2.0, is slightly higher than the counterfactual cumulative market share, implying that for these lowest efficiency star levels the MEPS resulted in an increase of cumulative market share. Additionally, the appliances rated with 2.5 and 3.0 stars lie below their respective counterfactual line, implying that the introduction of the MEPS in 1999 actually decreased their cumulative market share. The figure also illustrates that star efficiency levels 3.5, 4.0, and 4.5 appeared on the market after the implementation of the 1999 MEPS. These higher-efficiency levels have no counterfactual because they did not exist in 1993, the start year for the data and on which was based the model. Therefore, the impact of the 1999 MEPS was to phase out low-efficiency appliances (1.5 – 2.0 stars), decrease the cumulative market share of mid-efficiency appliances (i.e. 2.5 – 3.0 stars), and phase in higher efficiency appliances (i.e. 3.5 stars – 6.0 stars).

The period after the 1999 MEPS also reveals that the adoption rates flatten out between 2000 and 2003, the year in which the 2005 MEPS standards were announced. It appears that after having increased cumulative market share significantly to meet the standards before the implementation in 1999, manufacturers began idling and the market transformations begin to stagnate. This slow-down of the market could also be explained by the fact that the manufacturers are waiting to evaluate the success of their newly re-engineered appliances before rushing to re-engineer once again for the MEPS in 2005, as explained earlier[26]. Therefore, it appears that the early announcement of the 2005 MEPS may have disincentivized manufacturers

[26] (Ruderman & Levine, 1987)

to make improvements until they knew what the new standards would be, and that this announcement may have had a strong negative influence on the progress of the adoption rates.

Scenario 3: MEPS in 1999 and 2005

Scenario 3, in which the MEPS was implemented in both 1999 and 2005, is illustrated in Figure 7. This figure illustrates that from 2005 – 2009 the projected cumulative market share of all the star efficiency levels increase above their respective counterfactuals. While all cumulative market shares are above the counterfactual, it is important to note that star levels 3.5 and 4.0 made the largest jump in cumulative market share. Star level 3.5, for example, jumped from a cumulative market share slightly below 20% before the 2005 MEPS, to a market share slightly greater than 90%. Similarly, star level 4.0 jumped from below 10% to above 60%. The increase in cumulative market share of star levels 4.0 – 6.0 indicates that high-efficiency levels have been phased in and have penetrated the market. This increase illustrates that the 2005 MEPS resulted in the introduction of high-efficiency appliances to the Australian market and a phase out of low efficiency appliances. As mentioned in the interpretation of Scenario 2, it also seems as though the early announcement in 2003 of the 2005 MEPS may have slowed down the market and resulted in stagnating adoption rates.

Figure 7 also illustrates that while significant progress was made, the market transformation stagnates once again after the MEPS are introduced, but at a higher market share percentage. This may be, once again, the result of manufacturers waiting to see the success of their newly re-engineered appliances and to receive notice of the next set of MEPS revisions in 2010.

Individual (Non-Cumulative) Market Shares

Scenario 1: No MEPS in 1999 or 2005

Figure 8 illustrates the model predictions for individual market shares, assuming that no MEPS are implemented. As this scenario isolates the effect of the energy efficiency labels, this figure illustrates the hypothetical progression of domestic appliances using only the labeling scheme, before the MEPS are introduced.

This figure corroborates the findings for the cumulative market share predictions for scenario 1. The figure shows that while the labels alone allow the 3.0 star appliances (the most efficient appliances on the market at the time) to eventually dominate the market, the labels do not allow for high-efficiency appliances to ever penetrate the Australian domestic refrigerator market.

Scenario 2: MEPS in 1999

The individual market shares are shown in Figures 9 and 10, where Figure 9 shows the market share progression of low-efficiency appliances (1.0 – 3.0 stars) and Figure 10 shows the market share progression of high-efficiency appliances (3.5 – 6.0 stars). Figure 10 corroborates the findings from the cumulative market share model as well, demonstrating that the MEPS in 1999 served to phase in higher-efficiency appliances; Figure 9 illustrates the hypothesis that the 1999 MEPS phased out the lowest efficiency level of appliances and that the mid-range appliances began their slow decrease.This figure illustrates that appliances that are rated 2.5 and 3.0 stars initially increased with the 1999 MEPS, but then were ultimately phased out. The high-efficiency appliances began increasing rapidly, as shown in Figure 10, but 3.5 star appliances are also shown struggling to maintain their momentum and. This efficiency level is eventually phased out under this scenario.

Scenario 3: MEPS in 1999 and 2005

The individual market shares are shown in figures 11 and 12. Figure 11 illustrates the market share progression of low-efficiency appliances, along with the actual data points corresponding to this scenario. Figure 12 illustrates the market share progression of high-efficiency appliances. Both of these figures confirm the interpretation of the cumulative market share results from the model, and corroborate that the market initially stagnated after the 2005 MEPS. Whereas the low-efficiency appliances stagnated with very low market share percentages, the high-efficiency appliances stagnated with significantly higher market shares. However, these figures also illustrate that two years prior to the new MEPS implementation in 2005, the market share of low-efficiency appliances sunk dramatically and the market share of high-efficiency appliances increased at an impressive rate. These drastic drops and increases in market share reflect the “anticipation effect” of the manufacturers who are preparing for the new standards. Figure 12 also illustrates the introduction of an even higher efficiency level appliance (5.0 stars). The stagnation prior to 2003, as mentioned earlier, could also be the result of manufacturers waiting to see the success of their newly re-engineered products from the 1999 MEPS before beginning the transition required for the 2005 MEPS.

Energy Efficiency Improvement and Energy Savings

The energy efficiency improvement can be seen in Figure 13, where the annual weighted average energy consumption, measured in KWh, is plotted against time. As the curves decrease, the appliances consume less energy and is an indicator of improvements in energy efficiency. Figures 16A and 16B, respectively, illustrate the improvements in efficiency resulting from each of the MEPS. Figure 13 indicates that prior to the 2005 MEPS, the energy efficiency improvements had slowed down, which corresponds to the findings above describing a stagnating market prior to the 2004 MEPS. The energy efficiency improvement had slowed down so much that it was actually experiencing a slower rate of improvement than the counterfactual (seen by the energy consumption line that lies below the counterfactual). This implies that the energy efficiency improvement would have been better off without the 1999 MEPS. Despite the less than stellar improvements after the 1999 MEPS, Figure 13 illustrates that the introduction of the 2005 MEPS ultimately served to make drastic improvements in energy efficiency improvement. These drastic improvements are shown are illustrated by stark decrease in energy consumption after 2005.

Figure 14 illustrates the energy savings resulting from the MEPS in 1999 and 2005. The black points are the yearly weighted averages of energy consumption data points for all appliances, while the solid line is the weighted energy average of the modeled S-curves. The dotted lines are extrapolated S-curves: the dotted blue line represents the counterfactual (scenario 1: no MEPS in 1999 or 2005) and the dotted red line represents the counterfactual of the MEPS introduced in 1999 (scenario 2).

The energy savings from each MEPS can be evaluated by looking at the area between the solid green line and each of the counterfactuals. Figure 16A illustrates the area representing the energy savings resulting from the 1999 MEPS, shaded in yellow (the grey area is where there is a temporary loss of savings). The shaded blue area in Figure 16B illustrates the energy savings from the MEPS in 2005. As the figure illustrates, this area is quite large.

Figure 15 illustrates the cumulative energy savings over time, demonstrating that the implementation of both the 1999 and 2005 MEPS (represented by scenario 3) had a significant impact on the energy savings of Australian consumers.

It is interesting to note that the energy savings in Figures 14 – 15 are negative from 1999 – 2006 for both scenarios. A negative energy saving simply means that the annual average weighted energy consumption is decreasing more slowly than the counterfactual energy consumption. Once the energy savings are positive it means that the counterfactual is decreasing more slowly than the weighted average energy consumption, which is what we would expect once the MEPS are introduced. Figure 14 illustrates that the counterfactual is decreasing more rapidly than the weighted average energy through 2006 for Scenario 2 and through 2004 for Scenario 3. This difference is seen in Figure 13, where the blue counterfactual line is below the weighted average for Scenario 2.

IV. Sensitivity Analysis

Variations of the scenarios described throughout this analysis were performed to evaluate the sensitivity of the data. While the analysis interpreted above excludes 2004 from the model to remove the influence of a strong transition period, a sensitivity analysis was performed with data from transition periods to compare the results. An alternative method of modeling the transition periods was also included in the sensitivity analysis. This alternative method does not exclude transition years from the model but rather redefines the time periods such that they take into account the anticipation effect or transition period presumably created by the manufacturers. The last form of sensitivity analysis is to evaluate the model's sensitivity to the regression parameters that were used to parameterize the model.

Model Sensitivity to Transition Periods

Effects of Transition Periods

Sensitivity Analysis 1: Omitting 2004 to Model Transitioning to the 2005 MEPS

The transition periods are defined as being from the time the MEPS are announced to the time that the MEPS are introduced to regulate the market. The first transition period could be considered to be the period from 1996 through 1999 and the second transition period could be defined as 2003 through 2005. These periods of transition are problematic for the model for several reasons. Most importantly, the transition are short periods in which the rates of adoption of new appliances are significantly higher than the remainder of the time period, and this significant difference biases the regression coefficients, leading to an inaccurate determination of parameters for the model. The inclusion of the transition periods in the regression over-inflates the regression coefficients, and produces a model that is biased upwards. For instance, the model estimates and counterfactuals will predict higher cumulative market shares and individual shares than perhaps they should.

To evaluate the effect of the transition period, this analysis provides the results of the same model evaluation, but where 2004 is included in the model. The regression statistics are included in Table 2 of the Appendix for comparison, as is Figure 17, which illustrates the change in cumulative market shares resulting from the model's inclusion of 2004. As a result of the over-inflated regression statistics and model predictions, the implications of the introduction of MEPS vary slightly. First of all, and most importantly, the model prediction in this alternative does not show market stagnation before the 2005 MEPS, which is not consistent with what the actual data points say.

Additionally, when including 2004 in this model, this model incorrectly implies that the high-efficiency appliances penetrated the market in Period 2 more rapidly than they actually had, over-stating the changes that occurred in the market when the Australian added MEPS to be used jointly with energy efficiency labels. This upward bias of the MEPS under-states the impact that labels may have actually had on the market.

Sensitivity Analysis 2: Omitting 1999 to Model Transitioning to the 1999 MEPS

Like the inclusion of 2004 described above, including 1999 in the model could overstate the rate of adoption of new appliances prior to the MEPS in 1999. As such, this upward bias could overstate the effect that the labels had on the market and their impact is more difficult to isolate. The regression statistics from this model are provided in Table 3 of the Appendix and a figure is provided in Figure 18. Excluding 1999 from the model produced results that, like the inclusion of 2004, threw off results. The exclusion of 1999 resulted in cumulative market share rates that don't fit the data, and that indicate that there was an increase in market share of high-efficiency appliances, whereas in reality there was stagnation (shown by the data points).

One could argue that, based on the data points, 1997 through 1999 could all be considered transition years and should therefore be omitted from the model that was used in this analysis, as was the case for 2004. However, doing so would leave us with a very small sample size for Period 1 from which to determine the regression statistics and parameterize the model. Additionally, and more importantly, the transition leading up to the 1999 MEPS is slower and more progressive than that of the 2005 MEPS, and therefore the inclusion of the transition years has less of an impact in biasing the regression results.

Effects of Time Period Boundaries

An alternative method to evaluate the effects of transition periods is to include them in the model and redefine the time periods in such a way that they are delineated by manufacturers' response rather than when the MEPS are implemented. Assuming that the anticipation of the new MEPS begins 1 to 2 years before the implementation, it would be appropriate to define the new time periods as one of the following alternatives:

Alternative A

- Period 1: 1993-1998
- Period 2: 1999-2003
- Period 3: 2004-2009

Alternative B

- Period 1: 1993-1997
- Period 2: 1998-2002
- Period 3: 2003-2009

The results from these new time periods are illustrated in Figures 19 - 20. It is apparent from these figures that these alternative methods present both advantages and disadvantages to the analysis of adoption rates. Figure 19, illustrating the cumulative market share progression in alternative A, shows that this alternative does an adequate job of depicting the impact of the labels alone prior to the 1999 MEPS. This alternative also accurately depicts the market stagnation prior to the 2005 MEPS. However the market shares in the Period 3 are significantly different than the data and don't appear to accurately reflect market for Australian domestic refrigerators. For example, this figure illustrates that the cumulative market share of the lowest efficiency levels drops from near 100% prior to the 2005 MEPS to 70% after wards. Figure 20, on the other hand, does a better job at estimating the cumulative market share in Period 1, as this is closer to what the data and literature indicate was the case, but provides an inaccurate depiction of Periods 2 and 3.

Model Sensitivity to Parameters

This method consists of varying the regression coefficients by +/- one standard error determined in the regression to evaluate the sensitivity of the model to the parameters q and t_0. This sensitivity analysis reveals that the model is extremely sensitive to any variation in the parameters. Varying the regression coefficients by one positive standard error produces cumulative market shares all equal to 1 (in other words, all efficiency levels are saturating the market, which is impossible). Varying the regression coefficients by one negative standard error produces cumulative market shares all equal to 0, which we also know to be untrue.

V. Conclusion and Policy Implications

The implementation of the MEPS in 1999 and 2005 played a significant role in reducing Australia's energy consumption by domestic refrigerators. The increase in cumulative market shares after the announcement of the 1999 MEPS also indicates that the use of energy efficient labels, prior to the introduction of MEPS, was effective in encouraging sales of energy efficient appliances, but not to the same extent as the implementation of minimum energy performance standards. Once introduced in 1999, the MEPS served to phase out the low-efficiency appliances, completely eliminating the lowest efficiency level. These MEPS introduced higher-efficiency products onto the markets and accelerated their demand while also completely phasing out the lowest efficiency levels. However, the Australian program's success was not without some obstacles: the announcement of the 2005 MEPS two years prior resulted in a slow-down of market transformation between 2000-2003, reflecting the negative impact of the anticipation of the MEPS revision in 2005. In terms of policy, one could argue that the early announcement of the new standards in 2003 hurt the market for energy efficiency appliances by disincentivizing the manufacturers from making improvements to their products and allowing them to buy time until they knew more about the MEPS revisions.

While the early announcement in 2003 slowed down the market progress temporarily, Australia's aggressive approach of harmonizing with the world's strictest standards ultimately served its purpose by completely phasing-out the low-efficiency appliances and introducing additional high-efficiency appliances to the market. This goal of matching the U.S. energy efficiency performance standards for domestic refrigerators was certainly ambitious, as none of the models on the market in 2000 satisfied the requirements implemented in 2005 and the domestic refrigerator market required re-engineering. Despite these challenges, the goal was met successfully.

The approach set out in this paper provides a new methodology for more objective evaluation of energy savings of different program measures implemented at different points in time. Despite the analytical rigor offered by this methodology, it would appear that some understanding of the context of program implementation and the practical timetable of market reactions needs to be taken into consideration. For example, in the face of large energy reductions from new MEPS regulations, manufacturers have to start introducing new compliant models well ahead of the final implementation date. So some judgment is still required regarding the effective points where the policy measure started to have an impact. However, with further investigations and experience, it should be possible to provide common sense guidelines to allow the approach to be applied in a coherent manner in appropriate circumstances in a range of countries and for a range of different appliance types.

VI. Appendix: Figures and Tables

Figure 1: Raw Data of Cumulative Market Share of Australian Refrigerator-Freezers

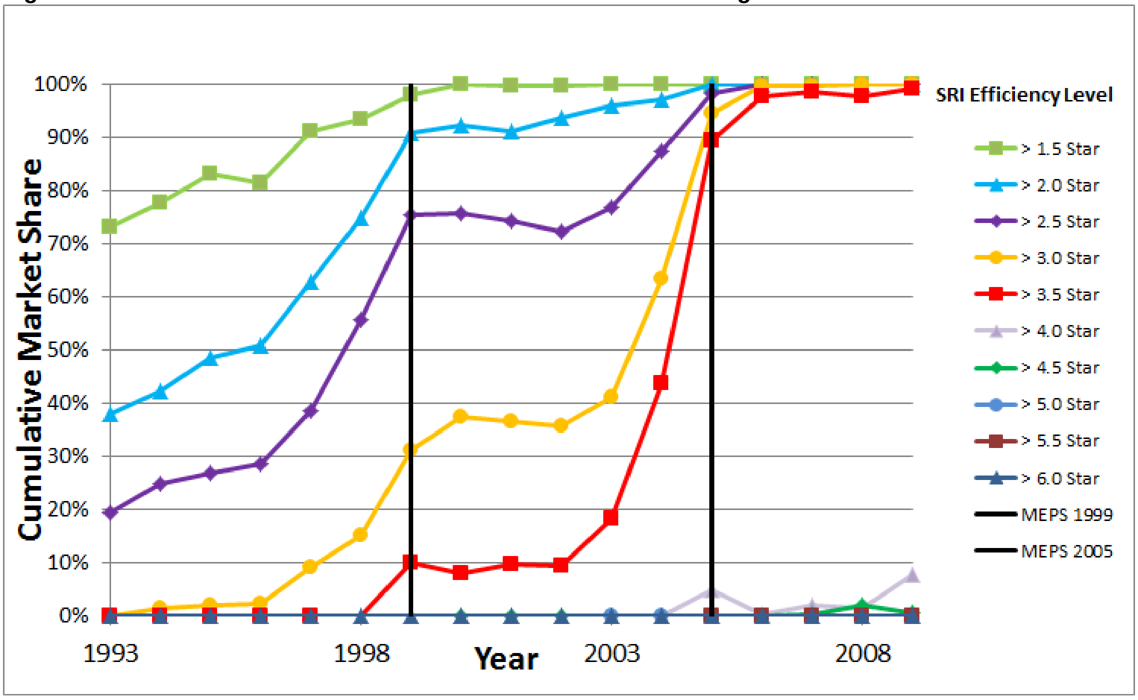

Figure 2: Linearized Data of Cumulative Market Share of Australian Refrigerator-Freezers

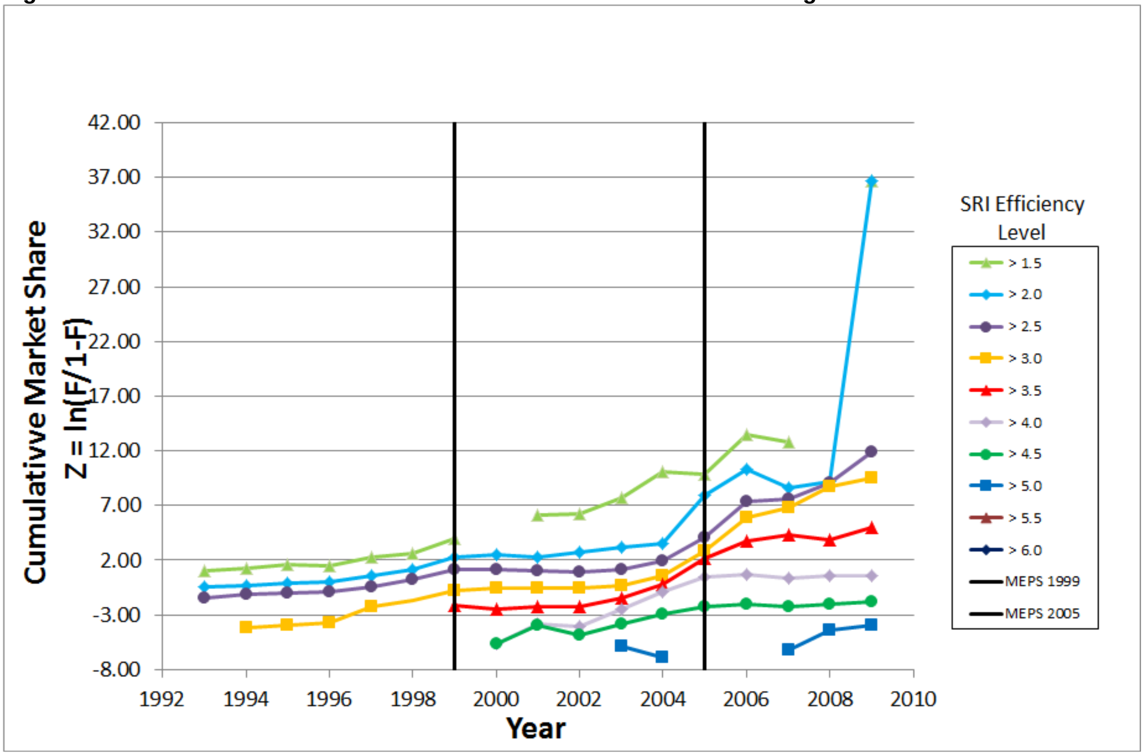

Figure 3: Linearized Data with Regression Lines

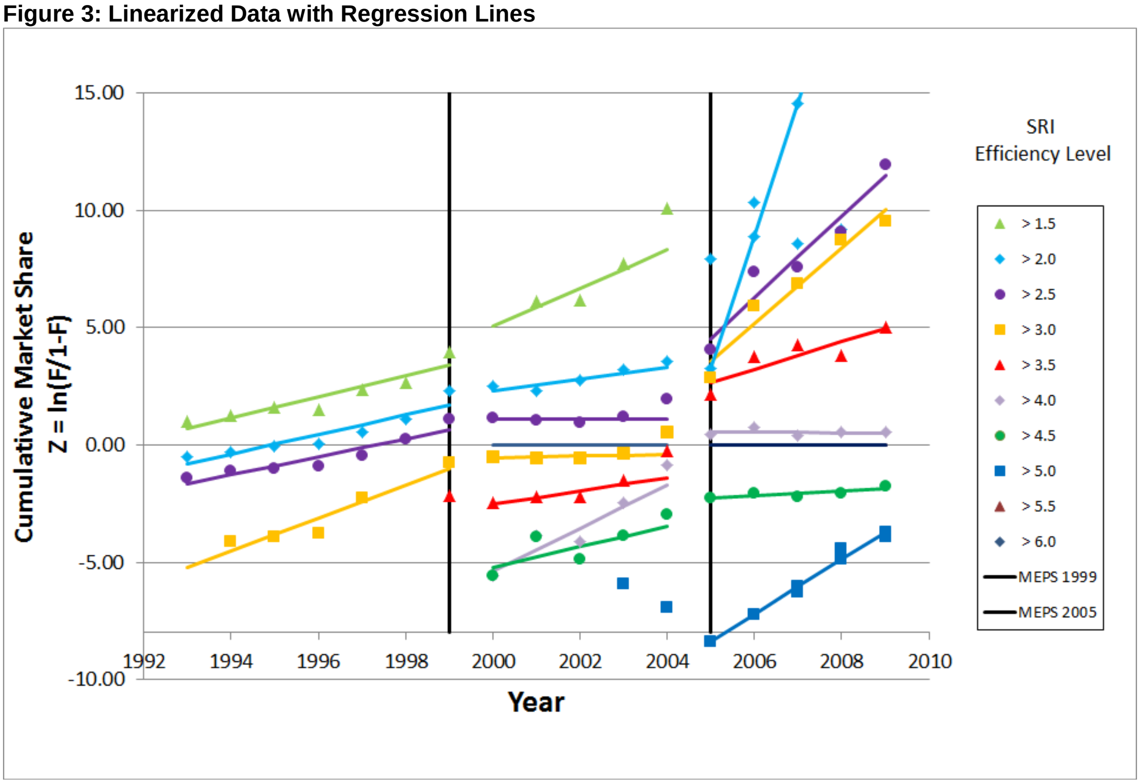

Figure 4: Overall Model Fit

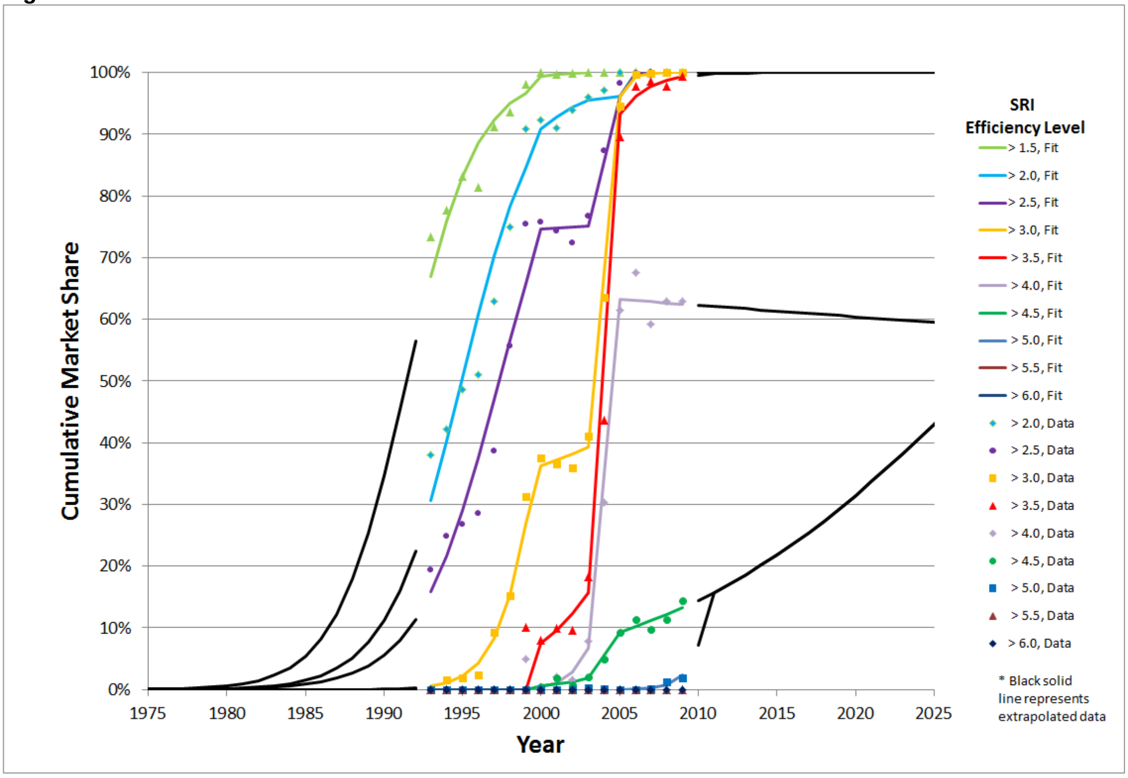

Figure 5: Adoption Curves of Australian Refrigerators-Freezers for Scenario 1

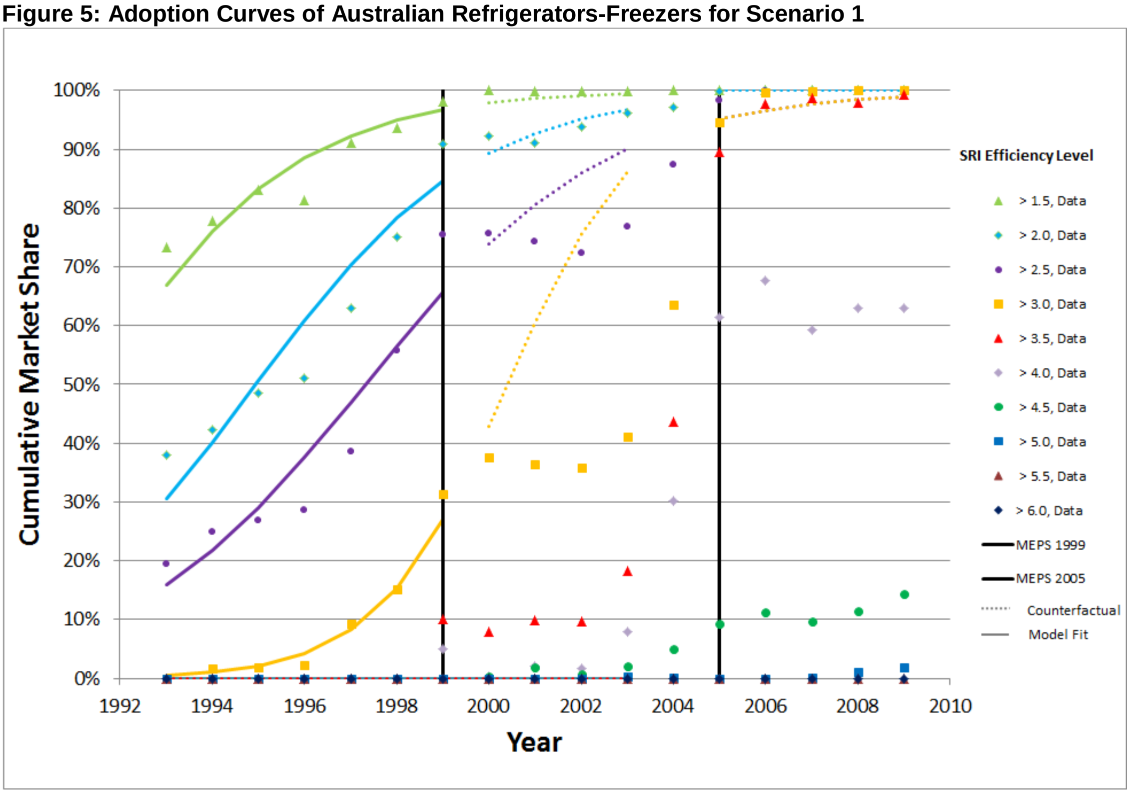

Figure 6: Adoption Curves of Australian Refrigerators-Freezers for Scenario 2

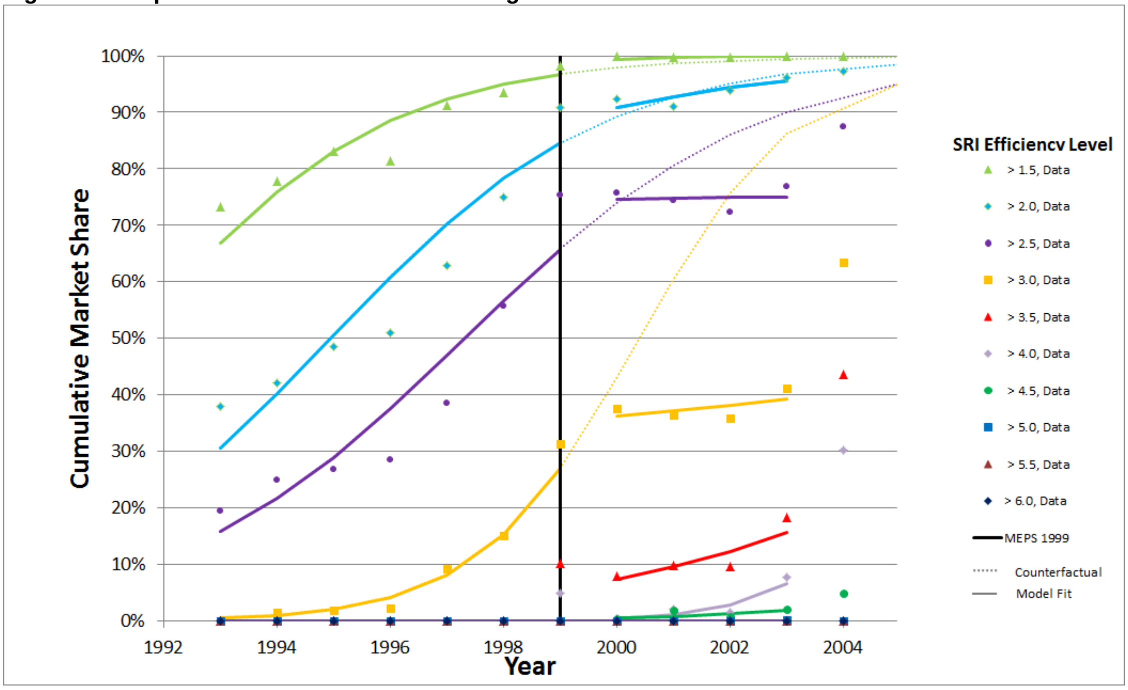

Figure 7: Adoption Curves of Australian Refrigerators-Freezers for Scenario 3

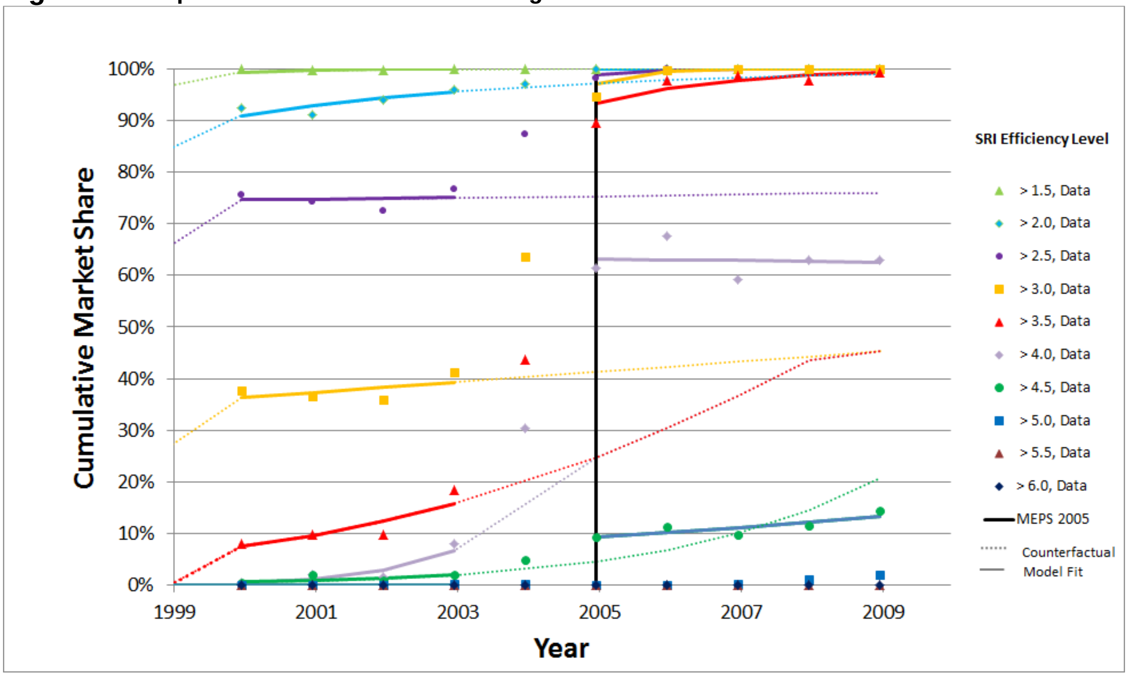

Figure 8: Individual Market Shares for All Australian Refrigerator-Freezers for Scenario 1

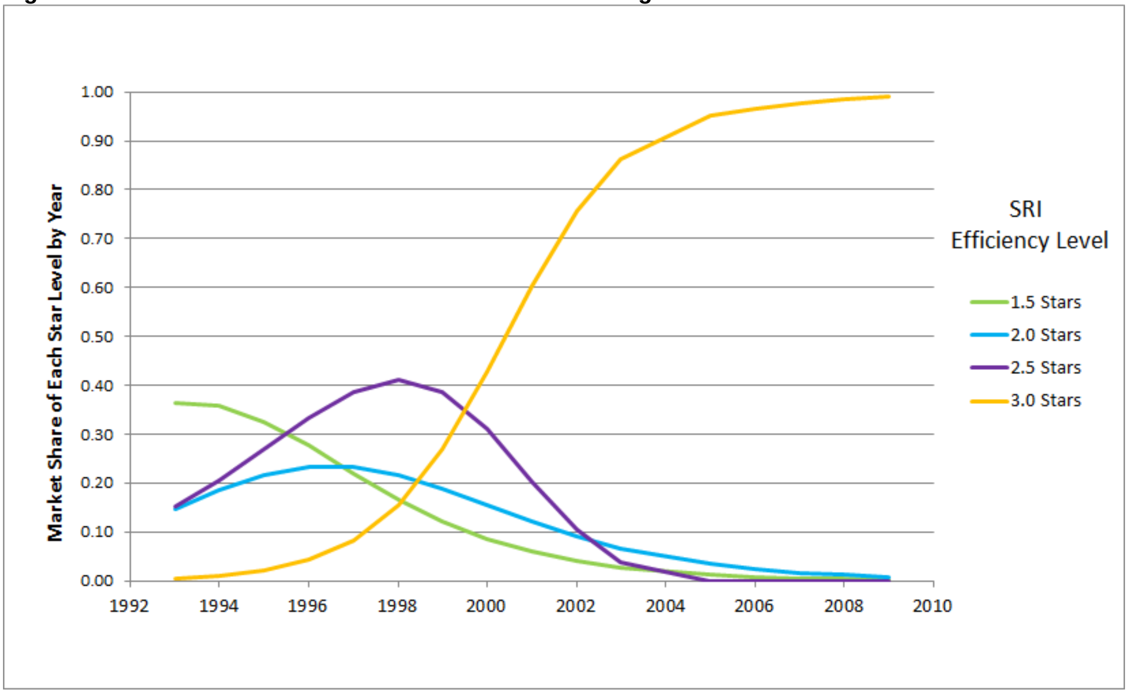

Figure 9: Individual Market Shares for Low-Efficiency Refrigerators for Scenario 2

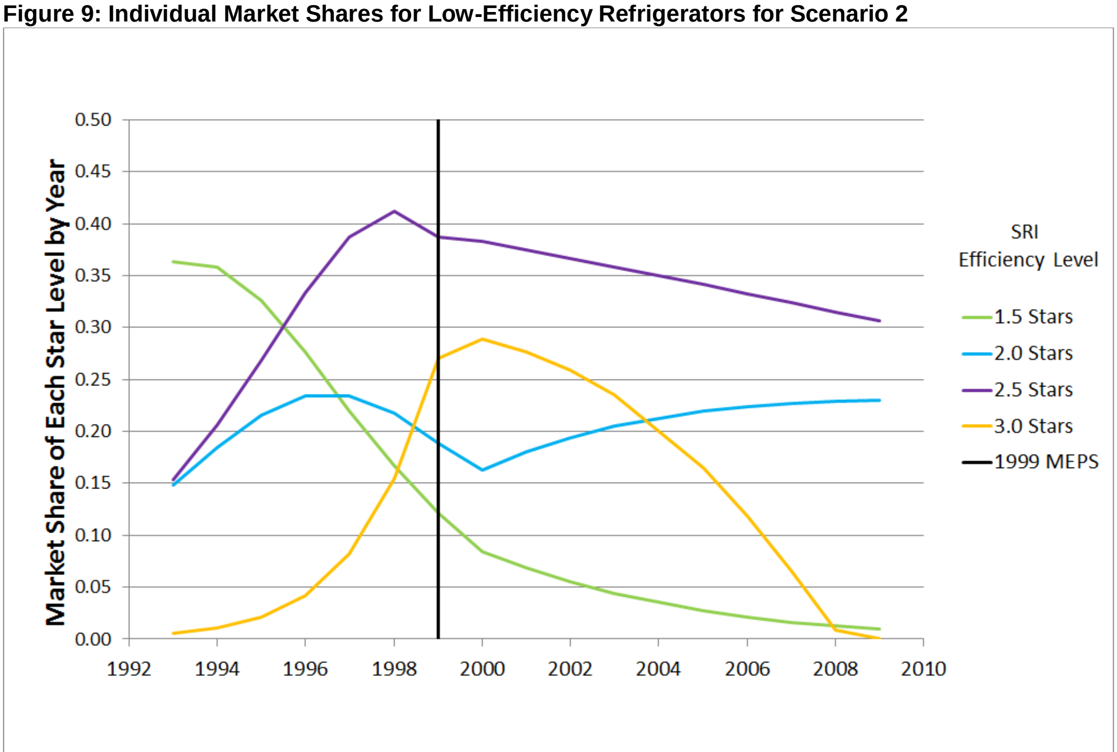

Figure 10: Individual Market Shares for High-Efficiency Refrigerators for Scenario 2

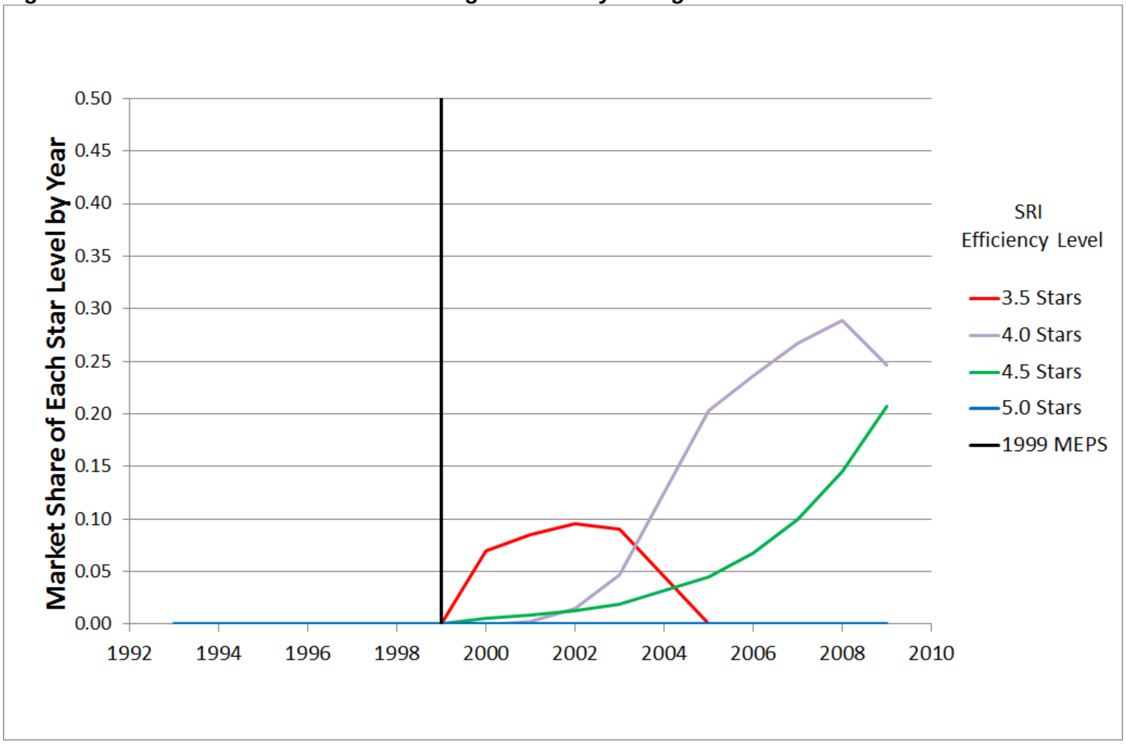

Figure 11: Individual Market Shares for Low-Efficiency Refrigerator for Scenario 3

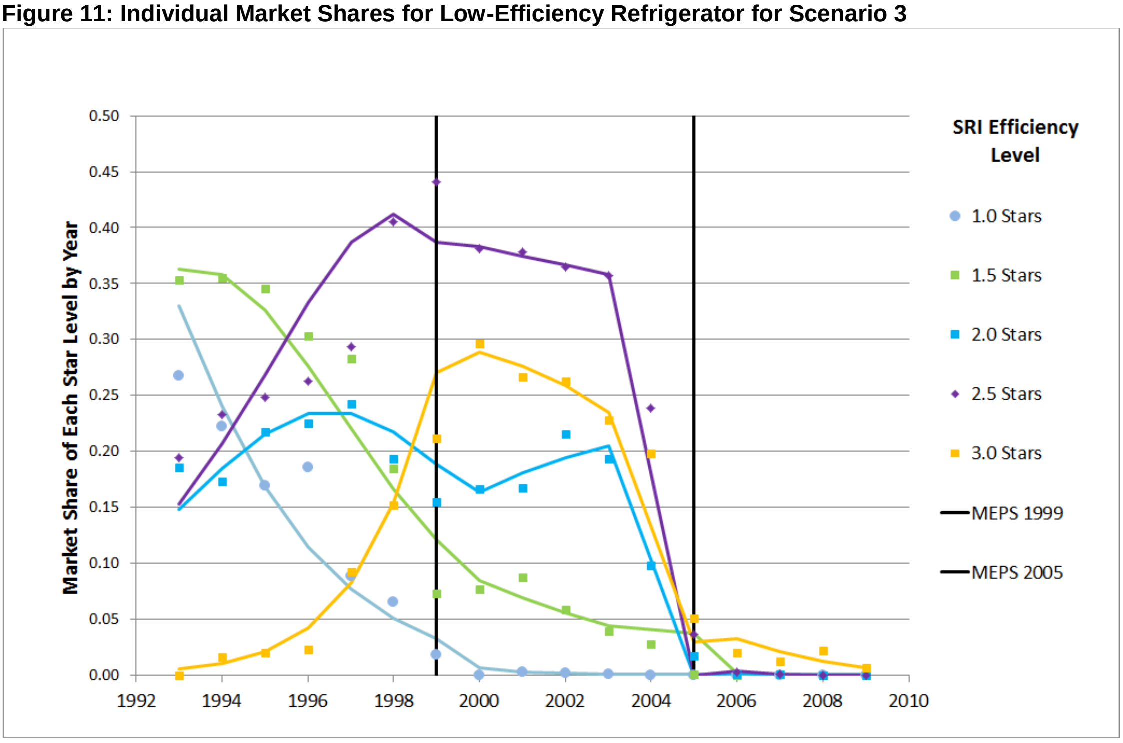

Figure 12: Individual Market Shares for High-Efficiency Refrigerator for Scenario 3

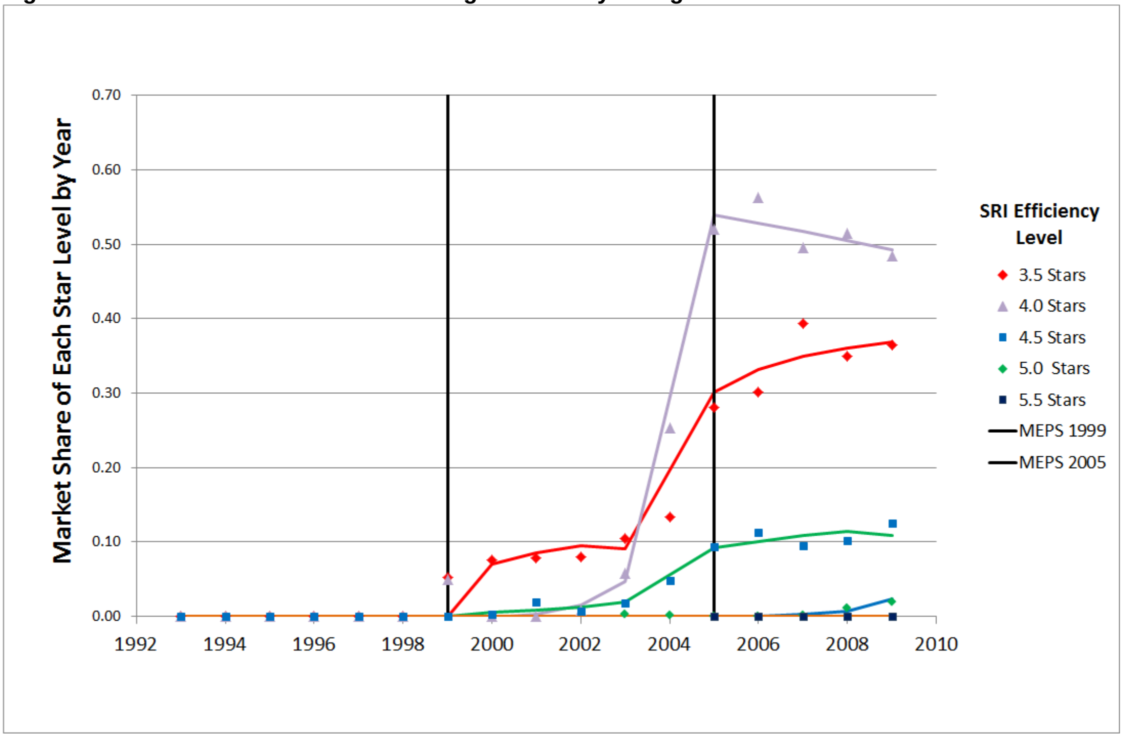

Figure 13: Annual Weighted Average of Energy Consumption (KWh/yr)

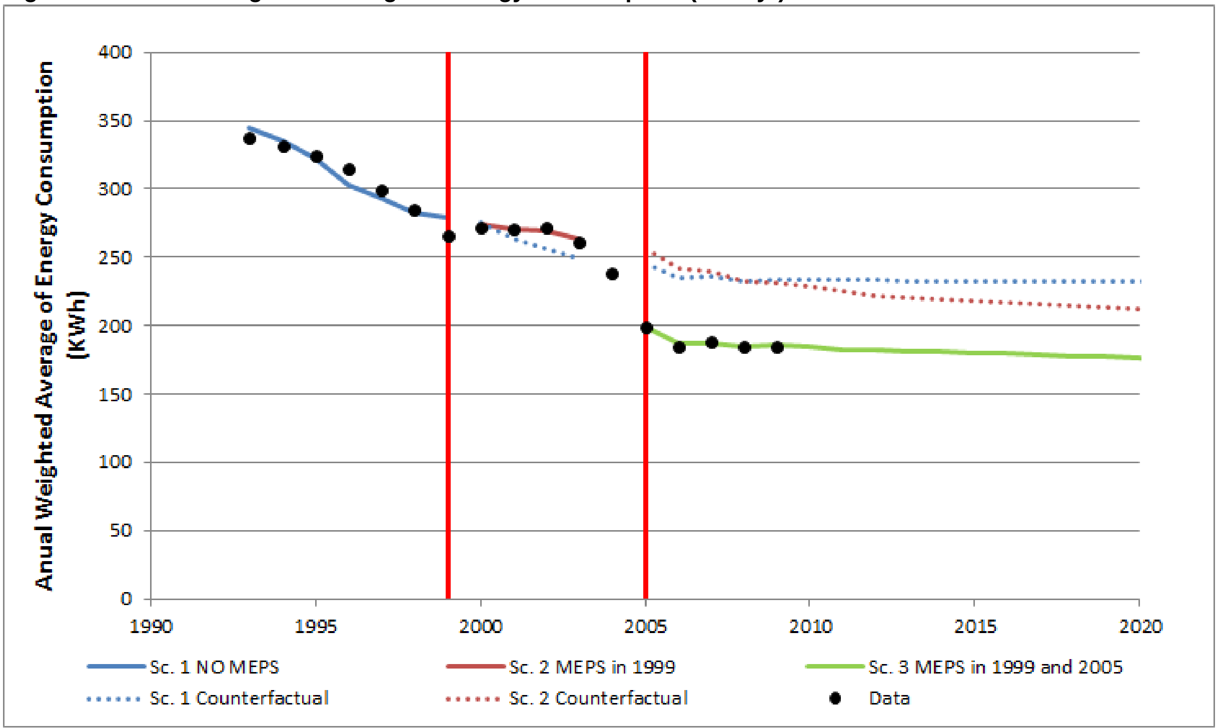

Figure 14: National Energy Savings

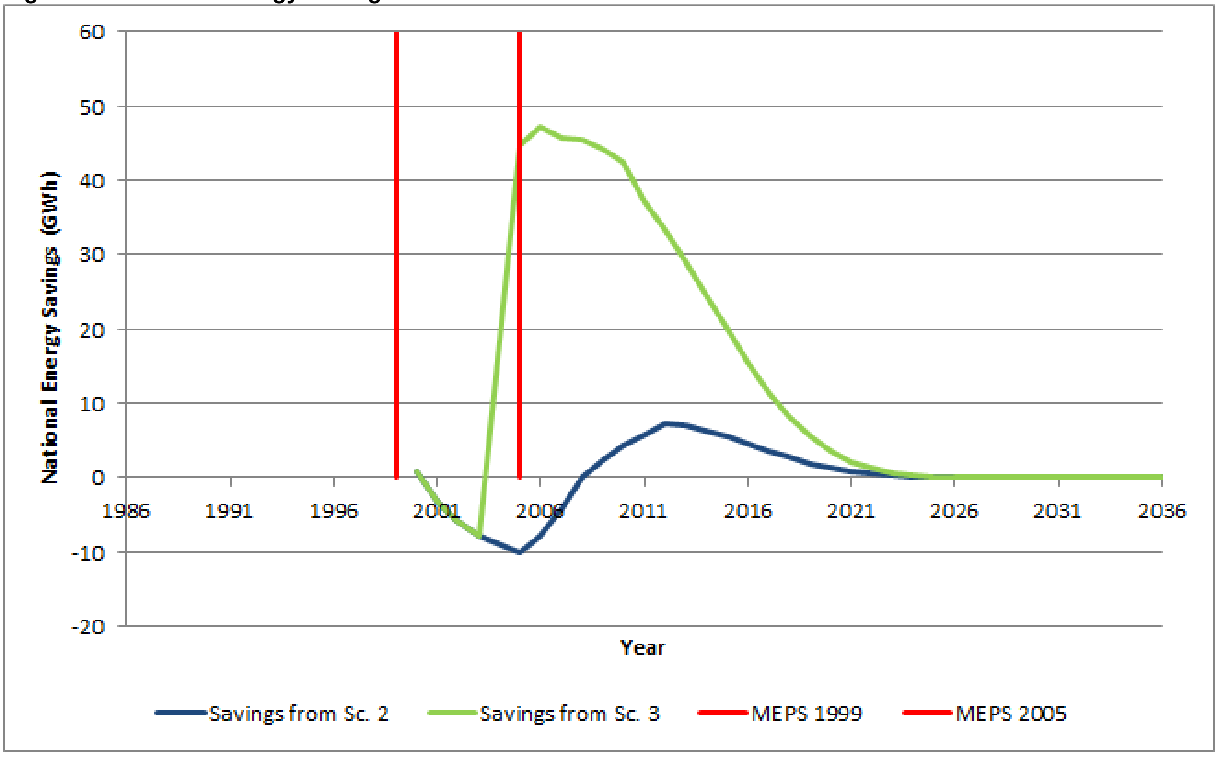

Figure 15: Annual Cumulative Energy Savings

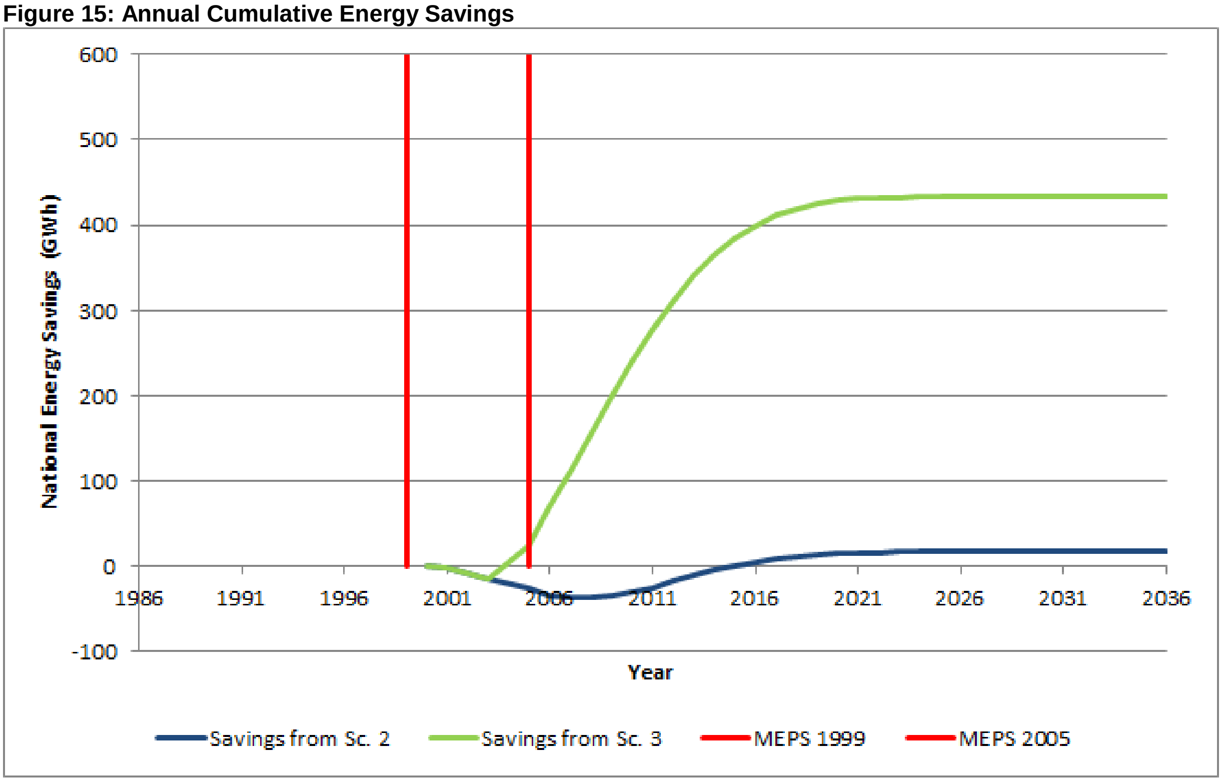

Figure 16A: Energy Efficiency Improvements due to 1999 MEPS

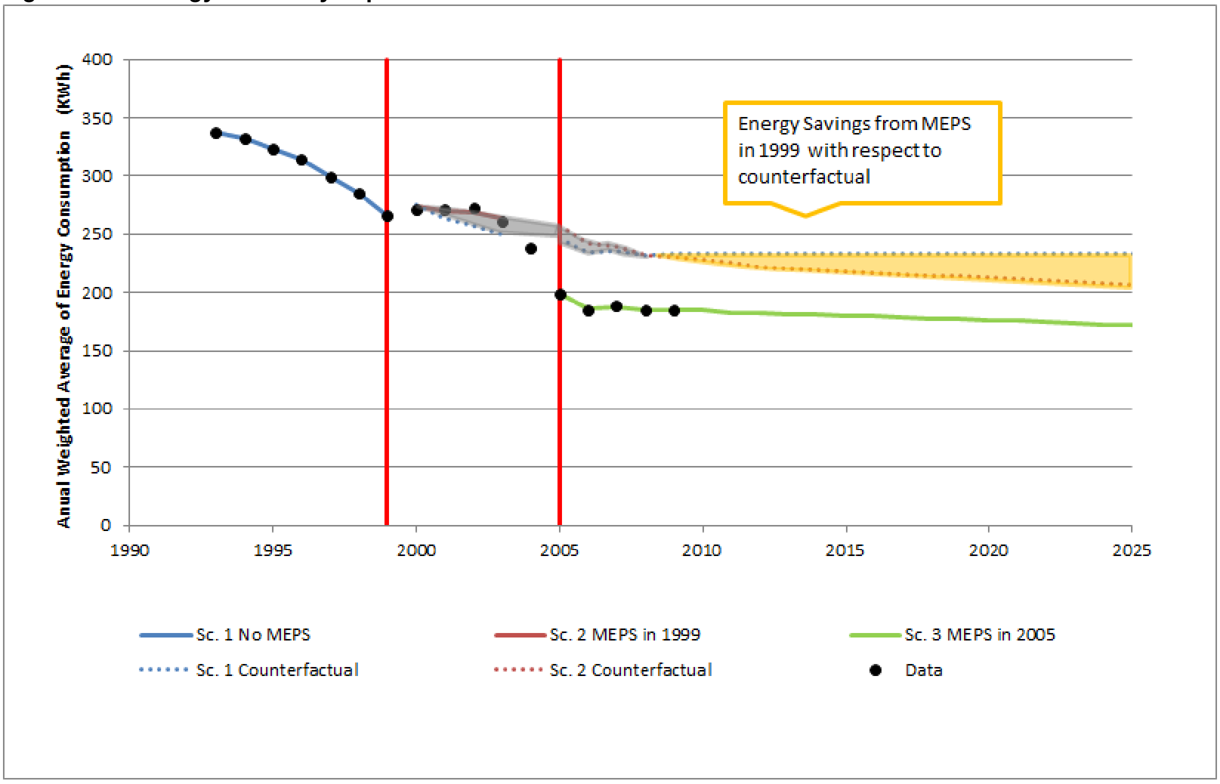

Figure 16B: Energy Efficiency Improvements due to 2005 MEPS

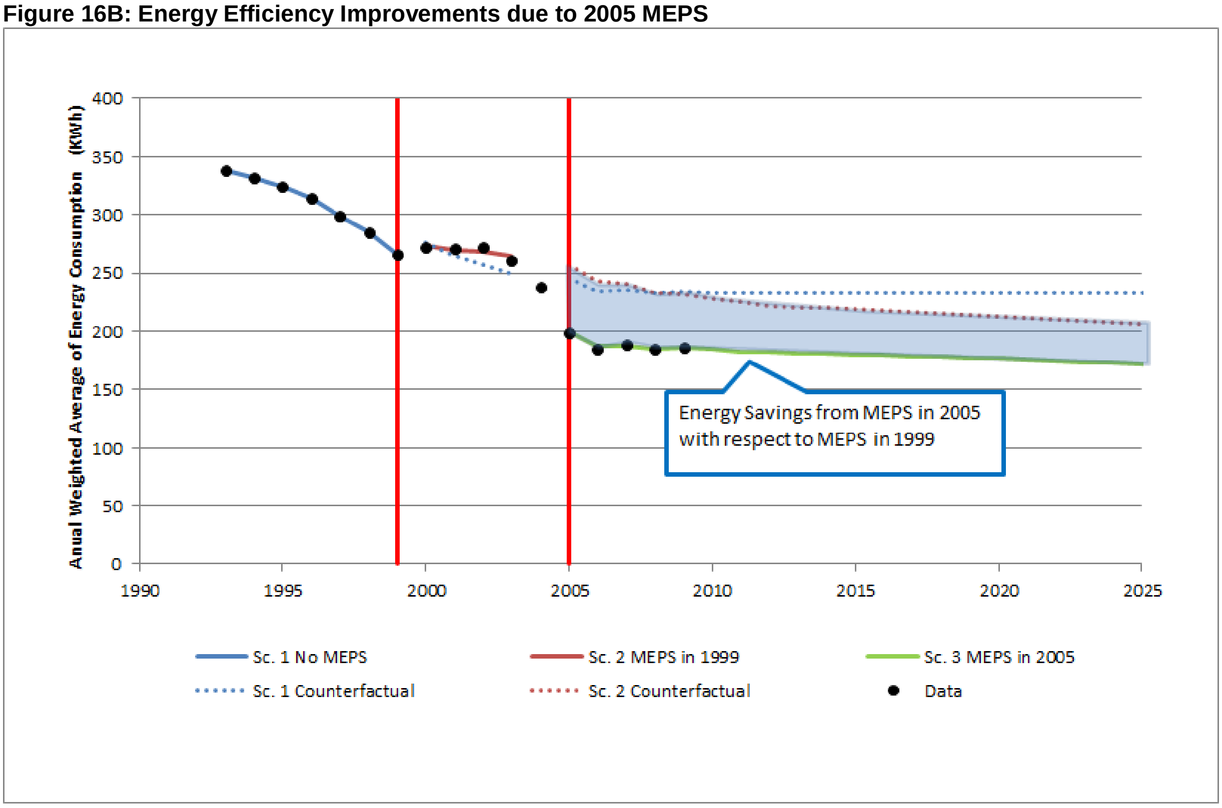

Figure 17: Adoption Curves of Refrigerators in Sensitivity Analysis 1

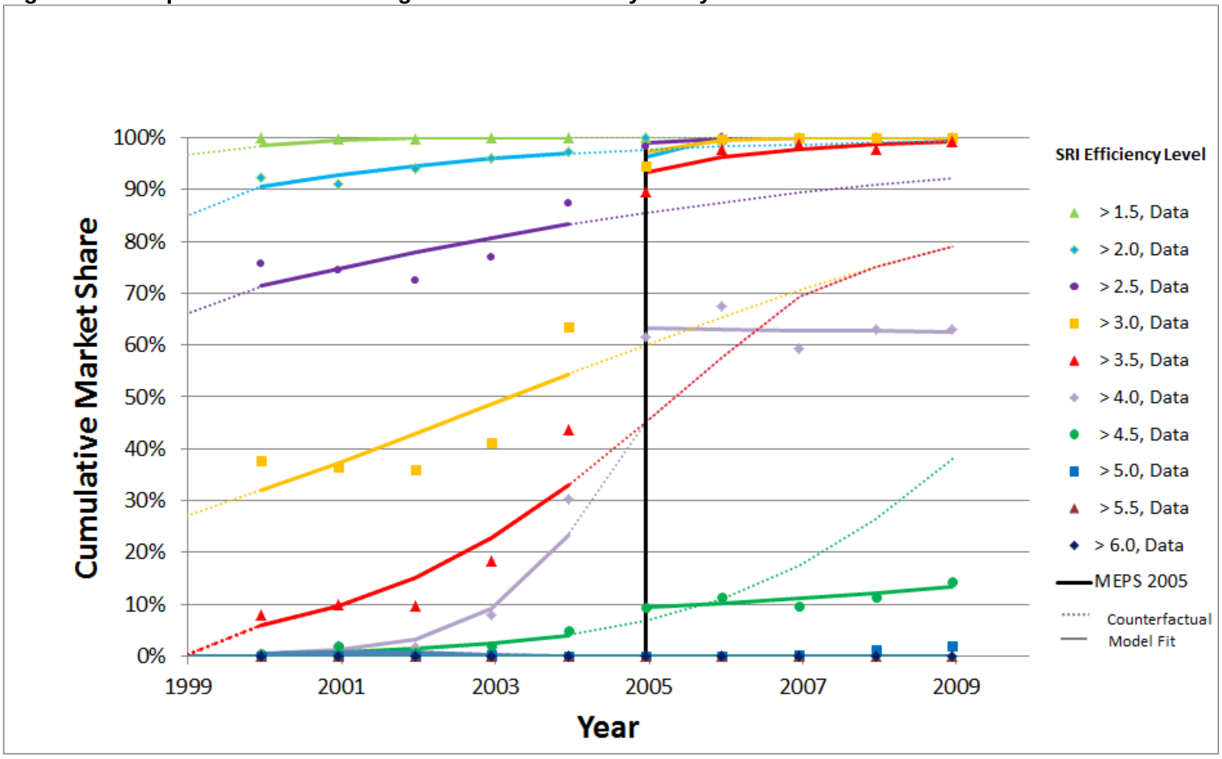

Figure 18: Adoption Curves of Refrigerators in Sensitivity Analysis 2

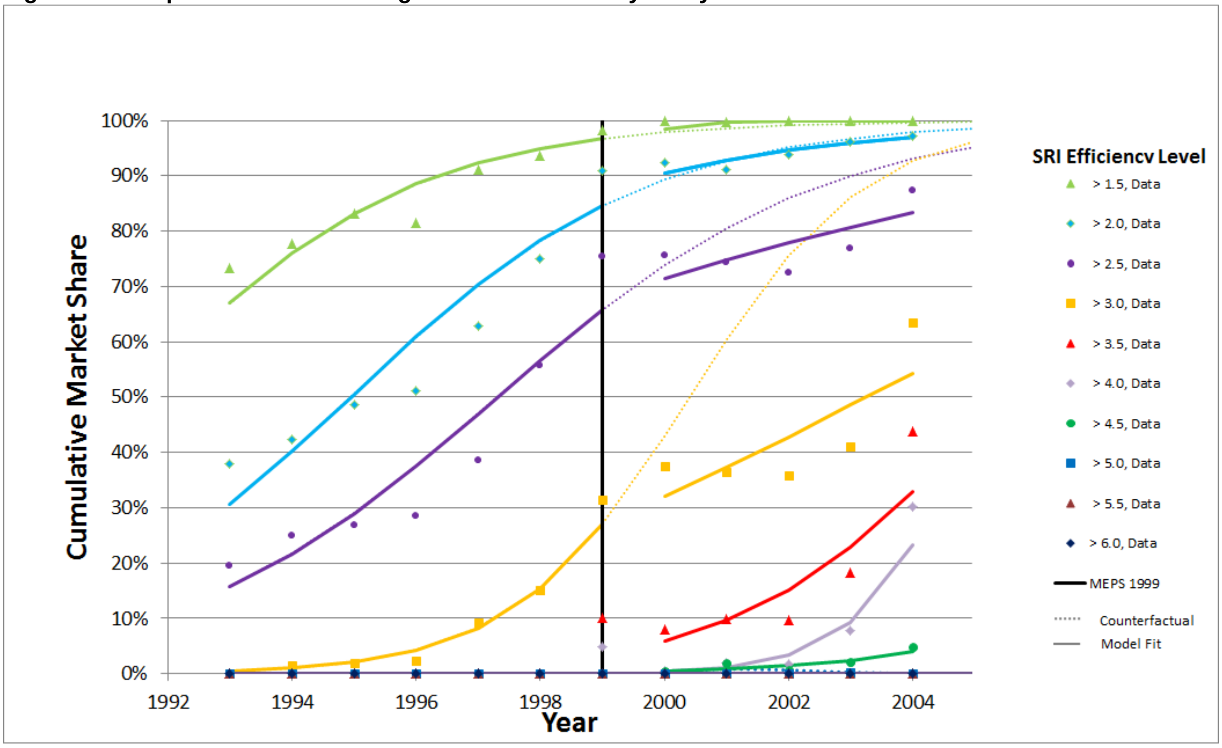

Figure 19: Sensitivity Analysis of Adoption Curves of Refrigerators (Alternative A)

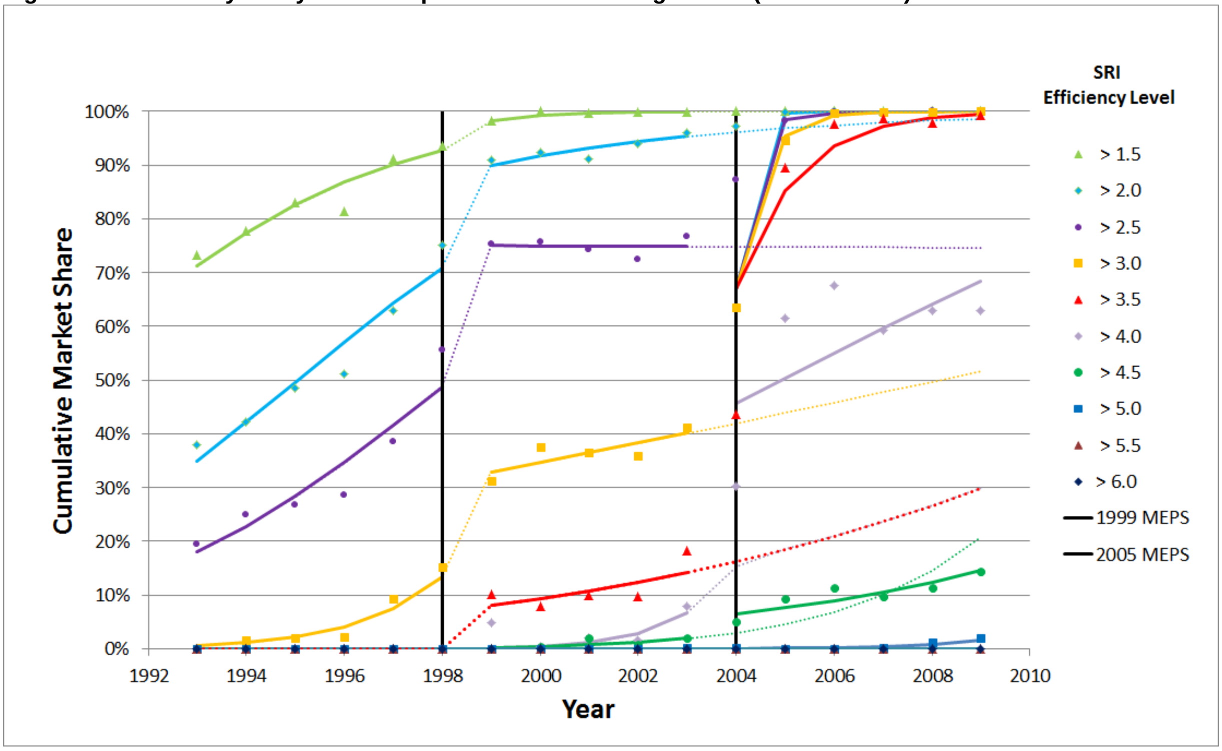

Figure 20: Sensitivity Analysis of Adoption Curves of Refrigerators (Alternative B)

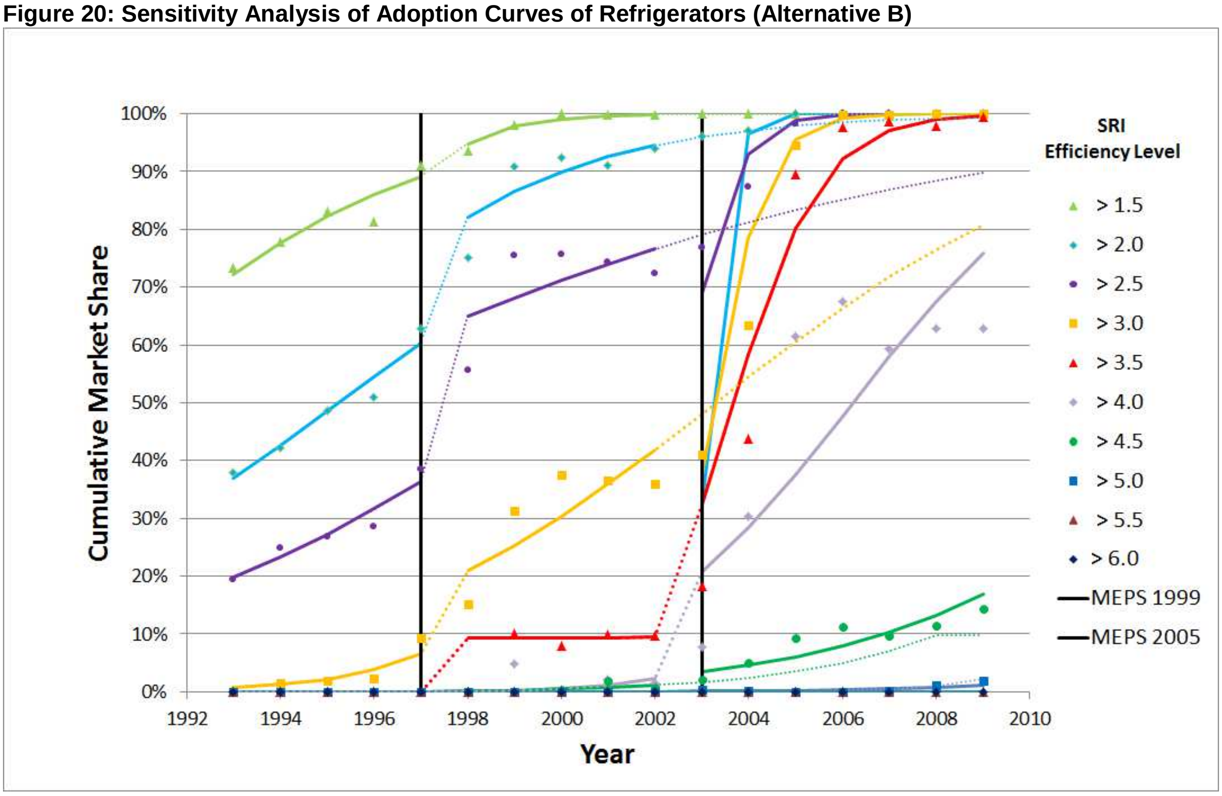

Table 1: Summary of Regression Statistics used to Parameterize the Model

	SRI EFFICIENCY LEVEL										
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
VALUES OF q											
Period 1	-	0.45	0.42	0.39	0.71	-	-	-	-	-	-
Period 2	-	0.81	0.25	0.01	0.04	0.28	0.92	0.43	-	-	-
Period 3	-	0.00	5.65	1.74	1.62	0.58	-0.01	0.10	1.17	-	-
VALUES OF C											
Period 1	-	-888.6	-838.4	-772.9	-1417.1	-	-	-	-	-	-
Period 2	-	-1624.2	-507.0	-15.2	-83.8	-567.2	-1841.8	-863.0	-	-	-
Period 3	-	36.7	-11329.6	-3493.4	-3238.0	-1166.7	16.4	-202.5	-2345.7		
VALUES OF t_0											
Period 1	-	1991.4	1994.9	1997.3	2000.4	-	-	-	-	-	-
Period 2	-	1993.8	1990.9	1867.3	2013.5	2008.9	2005.9	2012.1	-	-	-
Period 3	-	0.0	2004.4	2002.4	2002.8	2000.5	2073.4	2027.8	2012.2	-	-
R^2											
Period 1	-	0.86	0.86	0.87	0.93	-	-	-	-	-	-
Period 2	-	0.79	0.74	0.01	0.30	0.77	0.85	0.44	-	-	-
Period 3	-	1.00	0.52	0.93	0.95	0.76	0.01	0.66	0.90	-	-
Standard Error of q coefficient											
Period 1	-	0.08	0.07	0.07	0.10	-	-	-	-	-	-
Period 2	-	0.42	0.11	0.05	0.05	0.11	0.27	0.34	-	-	-
Period 3	-		3.16	0.28	0.21	0.19	0.05	0.04	0.38	-	-
Standard Error of constant c											
Period 1	-	158.00	148.83	131.72	190.09	-	-	-	-	-	-
Period 2	-	837.77	213.24	109.05	90.45	217.02	539.59	680.11	-	-	-
Period 3	-		6337.04	554.94	425.39	381.25	96.50	83.03	765.87	-	-
t-statistic											
Period 1	-	5.64	5.64	5.86	7.44	-	-	-	-	-	-
Period 2	-	1.95	2.39	0.15	0.92	2.60	3.41	1.26	-	-	-
Period 3	-	-	1.79	6.31	7.63	3.07	-0.16	2.41	3.06	-	-

Table 2: Regression Statistics from Model Including 2004

	SRI EFFICIENCY LEVEL										
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
	VALUES OF q										
Period 1	-	0.45	0.42	0.39	0.71	-	-	-	-	-	-
Period 2	-	1.34	0.30	0.17	0.23	0.51	1.09	0.54	-1.02	-	-
Period 3	-	6.69	5.65	1.74	1.62	0.58	-0.01	0.10	-	-	-
	VALUES OF C										
Period 1	-	-888.6	-838.4	-772.9	-1417.1	-	-	-	-	-	-
Period 2	-	-2685.2	-595.8	-345.6	-463.8	-1023.1	-2193.9	-1075.9	2028.8	-	-
Period 3	-	-13400.3	-11329.6	-3493.4	-3238.0	-1166.7	16.4	-202.5			
	VALUES OF t_0										
Period 1	-	1991.4	1994.9	1997.3	2000.4	-	-	-	-	-	-
Period 2	-	1996.9	1992.4	1994.7	2003.2	2005.4	2005.1	2009.9	1997.2	-	-
Period 3	-	0.0	2004.4	2002.4	2002.8	2000.5	2073.4	2027.8	-	-	-
	R^2										
Period 1	-	0.86	0.86	0.87	0.93	-	-	-	-	-	-
Period 2	-	0.88	0.87	0.50	0.58	0.80	0.92	0.69	1.00	-	-
Period 3	-	0.84	0.52	0.93	0.95	0.76	0.01	0.66		-	-
	Standard Error of q Coefficient										
Period 1	-	0.08	0.07	0.07	0.10	-	-	-	-	-	-
Period 2	-	0.36	0.07	0.10	0.11	0.15	0.19	0.21	-	-	-
Period 3	-	2.05	3.16	0.28	0.21	0.19	0.05	0.04		-	-
	Standard Error Of constant c										
Period 1	-	158.00	148.83	131.72	190.09	-	-	-	-	-	-
Period 2	-	718.35	133.40	200.97	225.64	291.63	372.10	411.56	-	-	-
Period 3	-	4115.91	6337.04	554.94	425.39	381.25	96.50	83.03		-	-
	t-statistic										
Period 1	-	5.64	5.64	5.86	7.44	-	-	-	-	-	-
Period 2	-	3.75	4.49	1.73	2.05	3.50	5.89	2.60	-	-	-
Period 3	-	-	1.79	6.31	7.63	3.07	-0.16	2.41	-	-	-

Table 3: **Regression Statistics from Model Omitting 1999**

	SRI EFFICIENCY LEVEL										
	1	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
					VALUES OF q						
Period 1	-	0.33	0.30	0.29	0.65	-	-	-	-	-	-
Period 2	-	0.81	0.25	0.01	0.04	0.28	0.92	0.43	-	-	-
Period 3	-	6.69	5.65	1.74	1.62	0.58	-0.01	0.10	1.17	-	-
					VALUES OF C						
Period 1	-	-650.3	-602.5	-585.8	-1291.4	-	-	-	-	-	-
Period 2	-	-1624.2	-507.0	-15.2	-83.8	-567.2	-1841.8	-863.0	-	-	-
Period 3	-	-13400.3	-11329.6	-3493.4	-3238.0	-1166.7	16.4	-202.5	-2345.7		
					VALUES OF t_0						
Period 1	-	1990.2	1995.1	1998.2	2000.9	-	-	-	-	-	-
Period 2	-	1993.8	1990.9	1867.3	2013.5	2008.9	2005.9	2012.1	-	-	-
Period 3	-	0.0	2004.4	2002.4	2002.8	2000.5	2073.4	2027.8	2012.2	-	-
					R^2						
Period 1	-	0.90	0.93	0.88	0.88	-	-	-	-	-	-
Period 2	-	0.79	0.74	0.01	0.30	0.77	0.85	0.44		-	-
Period 3	-	0.84	0.52	0.93	0.95	0.76	0.01	0.66	0.90	-	-
					Standard Error of q Coefficient						
Period 1	-	0.05	0.04	0.05	0.13	-	-	-	-	-	-
Period 2	-	0.42	0.11	0.05	0.05	0.11	0.27	0.34	-	-	-
Period 3	-	2.05	3.16	0.28	0.21	0.19	0.05	0.04	0.38	-	-
					Standard Error of constant c						
Period 1	-	109.53	84.65	106.49	268.27	-	-	-	-	-	-
Period 2	-	837.77	213.24	109.05	90.45	217.02	539.59	680.11	-	-	-
Period 3	-	4115.91	6337.04	554.94	425.39	381.25	96.50	83.03	765.87	-	-
					t-statistic						
Period 1	-	5.95	7.12	5.49	4.80	-	-	-	-	-	-
Period 2	-	1.95	2.39	0.15	0.92	2.60	3.41	1.26	-	-	-
Period 3	-	-	1.79	6.31	7.63	3.07	-0.16	2.41	3.06	-	-

Appendix: Mathematical Model Formulism and Assumptions

As mentioned in Section II, one of the main assumptions in this model is that each new MEPS implementation (occurring in both 1999 and 2005) triggers a change in the rate of change of the linearized market shares, thus changing the value q. Figure 5 illustrates the S-curves for all of the efficiency levels, as well as the data points that were used to estimate the parameters.

While the most important assumption is that of the changing values of q described above, there are also secondary assumptions on which the framework of the model depends. The cumulative market share model is defined in such a way that as the star efficiency level decreases the cumulative market share increases. For example, the cumulative market share of a 2.0 star appliance will always be greater (or equal), by definition, than the cumulative market share of a 4.5 star appliance. However, in a few instances, the mathematical formulism provided by the logistic function resulted in cumulative market share lines that intersected, allowing cumulative market share lines of higher starred appliances to exceed the cumulative market share lines of lower-starred appliances (for example, the cumulative market share line of a 4.5 star appliance that intersected the line of a 3.0 star appliance). By definition of cumulative market shares we know this to be impossible, so to resolve this issue an extra constraint was added to the model to make sure that the cumulative market share lines do not intersect. This constraint provides an upper bound to the cumulative market shares by restricting cumulative market shares by the cumulative market share of the star efficiency level directly below it (which produces a higher S-curve line). While this restriction was necessary addition to the model, it came into play in just a few instances and is not considered to have altered the results of the market share analysis.

Another important assumption in the calculation of energy savings is the retirement rate of refrigerators currently on the market. This rate determines the rate at which refrigerators are retired from the stock and replaced with newer models. Based on the literature[27], this retirement function for refrigerators is follows a normal distribution with a mean of 16 and a standard deviation of 4. This function was used in calculations determining the energy savings resulting from the MEPS in 1999 and 2005.

[27] (Energy Efficient Strategies, 2008)

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