

Does ENERGY STAR Affect the Provision of Energy-Efficient Goods?

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Abstract

Do voluntary energy efficiency certification programs affect the provision of efficient energy-using products in the market? I construct a model of firms' strategic responses to energy efficiency ecolabels to assess the effect of the labeling requirements on energy savings and energy efficiency market transformation. The first part of the paper provides graphical evidence suggesting that firms manufacture products that bunch at energy efficiency certification requirements. Following this result, the second part of the paper estimates the energy savings "attribution rates" of multiple specifications of the ENERGY STAR ecolabel for household appliances, and evaluates the program benefits for the product categories examined. I find that updates to ENERGY STAR certification requirements have a significant impact on the availability of high efficiency models. High efficiency appliances sold due to ENERGY STAR during the period examined in this paper will save approximately 25 petajoules over their lifetime.

Introduction

Energy-using residential products are regarded to be among the low-hanging fruits for energy efficiency improvements and greenhouse gas emissions abatement (Nauc ler and Enkvist 2009). Yet, while research shows large untapped societal benefits and savings for consumers who undertake residential energy efficiency upgrades, uptake of energy-efficient products remains fairly low. This phenomenon, often referred to as the “energy efficiency gap,” is frequently associated with behavioural problems such as “inattentiveness, loss aversion and reference dependence, and systematically biased beliefs” (Gerarden, Newell and Stavins 2015). For example, consumers may be *rationally* inattentive to energy costs and make apparently suboptimal purchasing decisions if energy-related information acquisition is costly.

In recent years, governmental entities have been increasingly attracted towards policies and programs that promote pro-environmental consumer behaviour and reduce the energy efficiency gap. A body of research proposes that information disclosure can be used as an alternative to regulatory instruments for mitigating pollution by improving consumer choices (e.g. Konar and Cohen 1997; Tietenberg 1998). When information concerning externalities associated to a good is difficult to acquire, green certification may lead to environmental benefits by correcting an informational market failure.

In addition to its impact on consumer behaviour, green certification may affect the provision of environmental quality if firms respond strategically to a certification program. Theoretical work suggests that gross substitutability of products, combined with price effects due to ecolabels, could have adverse effects on firms’ decisions to

provide green products, leading to an ambiguous outcome for environmental externalities (Kotchen 2006) and welfare (Amacher, Koskela, and Ollikainen 2004). Unfortunately, while theoretical research on ecolabels is abundant, empirical analysis of program benefits remain scarce. This paper adds to the empirical literature on ecolabels by conducting a benefit analysis of ENERGY STAR, a well-known voluntary ecolabel on the market for energy efficient products.

The analysis proceeds as follows. First, I develop a theoretical framework to provide the foundation for the empirical results. Second, using Canadian import transactions data for residential appliances, I present graphical evidence that manufacturers manipulate the efficiency level of products offered to meet energy efficiency thresholds. Third, using various revisions to the ENERGY STAR certification requirements, I derive for each product category and specification version an “attribution rate,” which is defined as the program’s contribution to energy savings through the provision of high efficiency (i.e. ENERGY STAR-certified) products on the market. Fourth, I test whether ENERGY STAR revisions affect product innovation on an energy dimension. Last, I estimate ENERGY STAR benefits in terms of energy savings.

The core of this paper – and also its main contribution – is the estimation of product-specific ENERGY STAR savings attribution rates utilizing Canadian data. To the best of my knowledge, this is the first attempt in Canada and elsewhere to measure the extent to which appliance manufacturers respond strategically to ENERGY STAR certification by examining import transactions. Previous work by Houde (2014b) investigated firm responses to ENERGY STAR certification by tracking monthly sales data of appliance retailers operating in the US. I believe that imports data capture firm

behaviour more reliably than sales data; the former is a measure of manufacturing decisions since products entering Canada are directly imported by the manufacturer (or a customs broker), while the latter includes a combination of newly manufactured products and retail stocks. We have no concerns about Canadian-made appliances affecting our results since Canada's major appliances market is dominated by a few foreign brands (e.g. General Electric, Whirlpool, Electrolux) and produced abroad.

The remainder of the paper has the following structure. The next section provides a primer on energy efficiency initiatives in Canada. Section 2 introduces the ENERGY STAR program, reviews the theoretical literature on ecolabels, and also discusses the relevant empirical work on the valuation of the ENERGY STAR certification. Section 3 develops a simple theoretical model that gives foundation for the empirical work that follows. Section 4 discusses key results of the analysis. Section 5 concludes the paper.

1. Energy Efficiency in Canada

In 1995, Canada's *Energy Efficiency Regulations* came into effect, setting Minimum Energy Performance Standards (MEPS) for a number of energy-using products. Since technological advancements occur over time, the Regulations are constantly updated to ensure that inefficient products are eliminated from the market. As of 2016, 12 amendments to the Regulations have been published in the Canada Gazette, and a 13th amendment covering 20 product categories is currently in its pre-publication stage.

In addition to enforcing regulatory standards for domestic energy-using products, Canada also administers non-regulatory policies for energy efficiency. A

prominent Canadian initiative for energy efficiency is its international partnership with the US Environmental Protection Agency (EPA) ENERGY STAR voluntary labelling program since 2001. Since its inception, ENERGY STAR has aimed to correct an informational market failure by reducing consumers' transaction costs associated with researching for efficient products available in the market. This information problem causes consumers to undervalue energy efficiency improvements, which in turn leads to negative externalities of increased energy use, i.e. financial loss to consumers and higher than socially optimal greenhouse gas emissions from the energy sector. The certification alleviates the information problem by providing consumers with a straightforward way to identify the most efficient products available at the time.

Products that voluntarily meet or exceed the ENERGY STAR standards at the time of manufacture are awarded the program label, which simply contains the ENERGY STAR brand logo (see Figure 1). ENERGY STAR relies on brand recognition to associate the label with high efficiency since the label itself does not inform consumers of product energy use. In addition to the ENERGY STAR label, energy-using products regulated in Canada must display visibly the mandatory EnerGuide tag, which provides a range of information about the energy consumption of the product (see Figure 2). For appliances, the EnerGuide tag contains: (1) the model's estimated annual energy consumption (AEC) in kilowatt hours (kWh); (2) a scale which positions the model compared with the most and least efficient models in the same class; (3) type and capacity of models within the same class; and, (4) the model number.

Another driver of energy efficiency in Canada is a third party certification managed by the Consortium for Energy Efficiency (CEE). CEE is a non-profit that works

closely with energy efficiency program administrators from various jurisdictions, including provincial governments in Canada. While ENERGY STAR sets one certification threshold for each product category, CEE allows for multiple tiers of certification. The lowest award, CEE tier 1, often aligns with ENERGY STAR performance levels. For some product categories, such as residential clothes washers, upper tiers are available for products that meet a standard above ENERGY STAR. On a monthly basis, CEE releases a list of qualified products available in Canada and the US.

2. Literature Review

In this section, I first introduce the ENERGY STAR program. Next, I discuss the theory and practice of ecolabels and review the empirical applications related to ENERGY STAR.

2.1 A Review of the ENERGY STAR Program

ENERGY STAR in Canada comprises programs in three areas: (1) product certification; (2) new homes certification; and, (3) commercial and institutional buildings benchmarking¹. Since the scope of this paper is limited to product labeling, the review will be mostly focused on that program area.

ENERGY STAR was conceived by the US EPA in 1992 as a voluntary certification program that would allow consumers to recognize the most energy efficient products available within a product category. Only computers and monitors were covered by the program when it was launched. By 1995, the ENERGY STAR label was available for a number of office products and residential heating and cooling equipment. In 1996, the

¹ More information on each program area can be found at <http://www.nrcan.gc.ca/energy/products/energystar/12519>

US Department of Energy (DOE) partnered with the EPA on the development of ENERGY STAR for other product categories including household appliances, which were introduced to the program that same year.

DOE maintains and periodically revises the ENERGY STAR criteria for household appliances. Updates to the performance requirements generally occur when ENERGY STAR products become prevalent on the market, but can also be triggered by revisions of regulatory standards or modifications to energy efficiency test procedures. On the event of launching a revision process, DOE notifies all ENERGY STAR partners and stakeholders, provides an initial market analysis, proposes a new requirement, and calls for comments. All formal comments are considered prior to the decision on the new certification requirements. A new specification will typically come into effect between six to twelve months after its final version is published at the ENERGY STAR website. The ordering and timing of these events imply that manufacturers have a good head start for developing new models that meet upcoming ENERGY STAR efficiency requirements. As it will become clear during my analysis, this is important for the validity of my claims regarding manufacturer response to ENERGY STAR certification.

Table 1 summarizes all of the ENERGY STAR updates to each product category examined in the paper, as well as US and Canada updates to federal minimum standards and test procedures. Each entry corresponds to the effective year of the event. The data used in my analysis covers the period from April 2008 – May 2016 and captures various relevant events that determine appliance energy efficiency in Canada. Since the table does not show the depth of the events, the most significant ones covered in the available data timeframe will be described below.

Clothes washers: ENERGY STAR for this product category was subjected to two revision processes during the timeframe of the analysis. The first revision introduced ENERGY STAR version 5.0, a two-phased update with effective dates in July 2009 for the first phase and January 2011 for the second phase. The second and most recent revision, version 7.0², entered into effect in March 2015. The certification requirements were based on two criteria: an energy efficiency factor and a water efficiency factor. Since my research concerns energy efficiency only, I will not examine the effects of ENERGY STAR on clothes washer water consumption. However, it is worth noting that water and energy factors are correlated, which means ENERGY STAR water efficiency requirements may hinder a manufacturer's ability to precisely manipulate a model's energy efficiency level.

Dishwashers: three ENERGY STAR specification revisions are covered by the data: version 4.1, effective August 2009; version 5.2, effective January 2012; and, version 6.0, effective January 2016. As with clothes washers, we focus our attention on energy efficiency requirements even though the specifications also include water efficiency requirements. Canada also amended its Minimum Efficiency Performance Standards (MEPS) for dishwashers in January 1, 2010. In the analysis section, version 4.1 was not included in my estimation for two reasons: first, the increase in efficiency required for this version was small relative to the previous version; second, the update on the MEPS stringency is a potential confounding factor in the estimation of an energy savings attribution rate for that particular version.

² Version 6.0 applies only to combination washer-dryers and is outside of the scope of this analysis.

Refrigerator-Freezers: two ENERGY STAR updates are covered by the period of the analysis: version 4.0, effective on April 2008; and, version 5.0, effective on September 2014. The effective date of version 5.0 coincides with an update to the US federal standards and test procedures. In my analysis, I explain the steps that I take in order to mitigate measurement error due to US test procedure and standards updates.

2.2 Theory and Practice of Ecolabels

A justification for the majority of ecolabeling models is that information asymmetries at play result in markets for “lemons” as described by Akerlof (1970). In this seminal paper, Akerlof shows that when buyers are less informed than sellers about the quality of products in a heterogeneous market, sellers have an incentive to advertise low-quality goods as having high quality. Consequently, Pareto-improving transactions will not occur because a now cautious buyer expects a lower average quality and also infers quality based on bidding prices.

In the context of green markets, ecolabels provide consumers with the ability to discriminate between otherwise unobservable characteristics about similar products’ environmental externalities. Upon verifying the environmental quality of a product, consumers may alter their purchasing decision and provide the public good (Kotchen 2006). For energy efficiency in particular, consumers’ decision to purchase highly efficient products (i.e. provide the public good) may also be motivated by private benefits in the form of energy bill savings in future periods. Thus, in the context of this paper, providing the public good can be treated as an “impure” green choice.

In order for ecolabels to be effective, producers must believe that consumers are willing to provide the public good. In his theory of warm-glow giving, Andreoni (1990) posits that charitable giving may not be the only factor influencing altruism; an “impure” altruism may contain elements of social pressure, guilt, or a desire for warm-glow which also drive the provision of the public good. Considering that energy efficiency is both a public and a private good, Wallander (2008) suggests that consumers are likely to have positive willingness to pay for energy efficiency ecolabels even without the intention to provide the public good. Indeed, the US EPA advertises ENERGY STAR with the claim that certified product simultaneously save money on energy bills and protect the environment.

The assumption that consumers are willing to pay more for green-certified products has been widely tested in studies that use revealed preference approaches. In these studies, researchers assume that consumers’ response to ecolabels can be revealed by their purchasing habits. The estimation typically uses market-level data and an econometric model to identify demand-side effects and consumer willingness to pay for ecolabels. For example, Bjørner *et al* (2004) employ a mixed logit model using sales data to find that consumers in Denmark are willing to pay 13% to 18% more for the Nordic Swan green certification on toilet paper. Below, I review several studies that use revealed preference approaches to examine the valuation of the ENERGY STAR label.

Eichholtz, Kok and Quigley (2010) utilize a revealed preference hedonic regression to find a large economic value to ENERGY STAR certification on commercial buildings in the US. Moreover, their results suggest that both energy savings and intangible elements such as improved corporate image seem to play a role in the

increased valuation of ENERGY STAR certified buildings. Walls, Palmer and Gerarden (2013) employ a hedonic regression to estimate a price premium for ENERGY STAR-certified new homes in three US cities and find that “homebuyers seem to either overpay for energy savings or value other aspects of certified homes beyond energy.”

Houde (2014a) conducts a robust estimation of consumers’ response to the ENERGY STAR label for appliances. He employs a structural demand model that considers various factors (e.g. electricity costs, presence of rebate programs, appliance sale price) that can explain how certification affects consumer decision-making. His conclusion is that consumers’ degree of information about energy efficiency is heterogeneous, ranging from completely uninformed to highly informed. Moreover, he finds that a significant share of consumers have a large willingness to pay for the ENERGY STAR label.

Houde (2014b) builds upon the results from Houde (2014a) and investigates whether firms respond strategically to ENERGY STAR. Using retail sales data from the US appliance market, he shows that the efficiency of models offered tend to bunch at the MEPS and the ENERGY STAR requirements. He then simulates an imperfectly competitive market with and without ENERGY STAR to (1) quantify the label’s effect on the distribution of high efficiency models and (2) quantify the welfare effects associated with the certification. The simulation results suggest that consumers’ high willingness to pay for ENERGY STAR induce firms to provide more certified models. In addition, while the scenario with ENERGY STAR yields large welfare gains when compared to the scenario without the certification, these gains come mostly from increased profits by firms which benefit from higher markups due to label-induced product differentiation.

Houde (2014c) evaluates the impact of ENERGY STAR rebate programs on consumers' purchasing decision. The main finding suggests that the majority of rebate claimants would have preferred ENERGY STAR-certified products even without the price incentive, indicating that energy efficiency rebates programs suffer from high rates of free-ridership. Houde and Spurlock (2015) use revealed preferences to investigate whether there is a relationship between efficiency standards/labeling and product innovation on a quality dimension. Their conclusion is that quality has discrete improvements over time, and these improvements coincide with the timing of a standard update or an ENERGY STAR revision.

An alternative methodology for estimating willingness to pay for green certification is to use a stated preference approach. In stated preference studies, researchers place consumers in a hypothetical marketplace and offer them various choices in order to infer consumer preferences and willingness to pay for a particular attribute. An advantage of the stated preference approach is its ease of implementation; while the data requirements for a revealed preference study is often prohibitive due to its proprietary nature, the data for a stated preference study can be constructed from surveys. Stated preference does have its shortcomings, however. Diamond and Hausman (1994) caution that the data collected from surveys is subject to a number of biases, due for example to its hypothetical nature and the framing of the questions that elicit preferences. Below, I review relevant works that use stated preference approaches to examine the effects of ecolabels on consumer purchasing decision.

An example for stated consumer preferences is the research of Aguilar and Vlosky (2007) on consumer willingness to pay for a hypothetical green certification on wood

products in the US. The paper uses survey data to elicit consumer willingness to pay for a certification that can ameliorate tropical deforestation. Using an ordered probit model, the researchers find that valuation of the hypothetical certification varies by income, with higher income respondents having higher willingness to pay. The lower bound of the stated willingness to pay (corresponding to the lowest income band) is estimated to be a 10% price premium.

Newell and Siikamäki (2013) conduct a survey to investigate the role of information labels, including ENERGY STAR, on consumer purchasing decision for high efficiency appliances. Their key result is that coarse information, as in the case of the ENERGY STAR label, is the most relevant factor determining cost-efficient appliance purchases. They also find that adding more complex information on energy costs and product externalities has a positive but small effect on consumer choice.

In sum, the empirical literature surveyed strongly suggests that consumers have positive willingness to pay for green certification. For ENERGY STAR in particular, the label valuation appears to be even higher than the private benefit of energy savings. This result is consistent with the claim that energy efficiency can be perceived as both a private and a public good. The literature also suggests that this positive willingness to pay leads to a price premium in the case of ENERGY STAR-certified appliances.

3. Methodology

I sketch a simple framework of manufacturers' strategic responses to the ENERGY STAR certification requirements in order to provide a theoretical foundation to the empirical approach later in the section.

3.1 Theoretical Framework

The first key assumption is that efficiency adjustments can be made without affecting product quality on other margins. These adjustments may be interpreted as costly component upgrades, which can be done within a relatively short time. This assumption can be empirically observed when, following a specification revision, manufacturers systematically improve on efficiency of existing models without making design alterations. An improved appliance model will typically have a very similar model number, such that the version history of a product line can be traced.

Define $c_j(e)$ to be model j 's production cost as a function of the chosen efficiency level e . We assume that costs are monotonically increasing and strictly convex in energy efficiency, i.e. $c_j'(e) > 0$ and $c_j''(e) > 0$. We also assume that $c_j \neq c_{j'}$, for $j \neq j'$, i.e. models are heterogeneous in energy efficiency costs.

The second key assumption is that a representative consumer cares about energy costs, but has a limited ability to observe appliance operational costs. At the time of a purchase, the consumer is certain about the appliance selling price but relies on the ENERGY STAR label to infer high efficiency from a model. Thus, the mapping of efficiency into consumers' perceived appliance lifetime costs has a sharp discontinuity at the ENERGY STAR certification threshold. It follows that consumer willingness to pay for energy efficiency is notched upwards at the ENERGY STAR threshold. A positive fraction δ of the notch on willingness to pay can be interpreted as the ENERGY STAR price premium.

Let $t = 1, 2, \dots$ represent time, and $j = 1, 2, \dots, n$ represent models from a manufacturer of a given product category. Define e_t^{reg} as the category's Minimum Efficiency Performance Standards (MEPS) at time t , and h the contemporaneous efficiency requirement for awarding a model with the ENERGY STAR label. Under assumption two, there exists a reward δ for the manufacturer in setting e_j above the current ENERGY STAR level h , and this reward is identical for all $e_j > h$. Now, the problem of a manufacturer is to find a vector of efficiency levels e that maximizes net benefits for each model j . We consider two possible scenarios:

Scenario 1: the business as usual (BAU) case in the absence of the ENERGY STAR program:

$$e^{BAU} = \max_{\{e_j\}_{j=1}^n} \sum_{j=1}^n \Pi(e_j) = [p_j - c_j(e_j)]q_j, \text{ s.t. } e_j \geq e_t^{reg} \forall j \quad (1)$$

Scenario 2: the ENERGY STAR (ES) scenario, in the presence of the program:

$$e^{ES} = \max_{\{e_j\}_{j=1}^n} \sum_{j=1}^n \Pi(e_j) = [p_j - c_j(e_j)]q_j + 1_{ES}(j)[\delta q_j], \quad (2)$$

$$\text{s.t. } e_j \geq e_t^{reg} \forall j$$

where 1_{ES} is the ENERGY STAR indicator function defined below:

$$1_{ES}(j) = \begin{cases} 0, & \text{if } e_j < h_t \\ 1, & \text{if } e_j \geq h_t \end{cases} \quad (3)$$

Note that it is possible that the price of model j is different in the BAU and ENERGY STAR scenarios. Houde (2014b) suggests that ENERGY STAR allows firms to differentiate products on the energy dimension, leading to higher markups on both certified and non-certified models when compared to the BAU case.

Finally, we say that for each model j , the mapping of e_j to net benefits $\Pi(e_j)$ is strictly concave and has a global maximum for both the BAU and ES cases.

Our objective is to calculate the share of models whose efficiency levels are different in the presence and absence of the ENERGY STAR program. Let there be three possible types for each model. Model j is:

Type α if:

$$\begin{cases} e_j^{ES} \geq h; & \text{in the presence of ENERGY STAR} \\ e_j^{BAU} < h; & \text{in the absence of ENERGY STAR} \end{cases} \quad (4)$$

Type β if:

$$\begin{cases} e_j^{ES} \geq h; & \text{in the presence of ENERGY STAR} \\ e_j^{BAU} \geq h; & \text{in the absence of ENERGY STAR} \end{cases} \quad (5)$$

Type γ if:

$$\begin{cases} e_j^{ES} < h; & \text{in the presence of ENERGY STAR} \\ e_j^{BAU} < h; & \text{in the absence of ENERGY STAR} \end{cases} \quad (6)$$

If model j is type α , under the previously stated assumptions, the optimal efficiency level e_j^{BAU} in the absence of ENERGY STAR would have been below the ENERGY STAR threshold. Therefore, the share s_α of α -type models informs us of models that are highly efficient due to the ENERGY STAR program. Unfortunately, the

distribution of efficiency offered at time t only allows us to observe whether a model meets or not the certification efficiency requirement. In other words, while a snapshot of the distribution of efficiency offered can inform us of the ENERGY STAR market share of models such that $e_j \geq h$ (that is, $s_\alpha + s_\beta$), it cannot distinguish between types α and β .

I propose that we can observe the share s_α of models that are of type α with respect to an upcoming specification h' . To do so, let's first consider an ES scenario represented by a future period $t + 1$ when specification h' comes into effect. We can then consider the current period t as our BAU scenario, since it corresponds to a time where h' is not yet effective. Given the assumptions that the price premium δ is homogeneous for all models, and that costs are convex and monotonically increasing in efficiency, we can assume that a model which was of type γ during the specification h effective at time t will continue to be type γ after the specification revision at time $t + 1$. Now, from equation (4), we have that a model will be of type α if the two conditions $e_j^{t+1} \geq h'$ and $h \leq e_j^t < h'$ are satisfied. Similarly, equation (5) indicates that a model will be of type β if $e_j^{t+1} \geq h'$ and $e_j^t \geq h'$.

We can then elicit s_α by observing changes in the distribution of efficiency offered before and after an ENERGY STAR specification revision. The share s_α would correspond to the mass of soon-to-be decertified ENERGY STAR models that move above the new threshold h' between periods t to $t + 1$ in order to maintain the label. Let j correspond to models such that $h \leq e_j < h'$ and j' corresponds to models such that $h \leq e_{j'}$. The share s_α can be expressed in the following way:

$$s_{\alpha} = \frac{\sum_j X_{jt}}{\sum_{j'} X_{j't}} - \frac{\sum_j X_{jt+1}}{\sum_{j'} X_{j't+1}}, \quad (7)$$

where X_{jt} is the number of models j at time t . In the following section, we will build upon equation (7) in order to estimate energy savings attributable to the ENERGY STAR program.

3.2 Data and Empirical Approach

Canada's *Energy Efficiency Regulations* require that dealers submit an energy efficiency report for energy-using products imported into Canada. From these reports, the Department of Natural Resources Canada (NRCan) collects data including product type, manufacturer and model number, and information regarding efficiency and energy consumption levels. A directory of models currently available in the Canadian market can be extracted from an online database maintained by NRCan.

The data used in my estimation consists of appliance import transactions from the Canada Border Services Agency (CBSA) which have been combined with NRCan's appliance directory in order to associate each transaction with the imported model's efficiency characteristics. The resulting dataset is an unbalanced panel covering the period from April 2008 to May 2016 for three appliance types: clothes washers, dishwashers, and refrigerators. The unit of time for the series is a quarter of a year. The last quarter is cut short, starting from April 01, 2016, and ending on different days of May 2016 depending on the product category. For each quarter, I observe the number of units imported of each model and the model's respective energy efficiency metric. For

my analysis, I also constructed a variable “efficiency factor” which indicates the percentage difference between a model’s efficiency level and the MEPS that applies for that product.

I start by providing graphical evidence that appliance manufacturers respond to ENERGY STAR by “bunching” above the certification requirement. The idea of bunching is that the ENERGY STAR efficiency criterion represents an incentive threshold and generates excess mass in the distribution of efficiency at the certification requirement. My approach is closely related to Houde (2014b), who demonstrates that the distribution of efficiency levels of appliance models tend to bunch on the MEPS and the ENERGY STAR thresholds. The key difference from Houde is that the unit of measurement for my dependent variable is the number of shipments instead of the count of models. The advantage of this shipment-weighted distribution is that it better represents the production decision of manufacturers. My work also relates to Sallee and Slemrod (2012), who shows that automakers respond to a stepwise tax on fuel-efficiency by manipulating vehicle fuel economy ratings in order to reduce the tax burden.

Figures 3-6 show the evolution over the years of empirical distributions of efficiency levels for each product category. Product efficiency is measured relative to the Canadian MEPS, which has a locus at the graph origin. The ENERGY STAR level effective in each year corresponds to a dashed reference line. For clothes washers, an additional dotted line identifies a change in the US federal standard, and a short-dashed line is added to indicate the CEE tier 3, which is a relevant third-party certification on the market for this particular product.

Clothes washer specifications were revised in 2009 and 2011 (version 5.0), and 2015 (version 7.0). Figure 3 shows that top-loading clothes washer shipments are mostly clustered at the MEPS and CEE tier 3 levels for the years between 2009 and 2014. In 2015, US standards, ENERGY STAR requirements and CEE tier 3 requirements were updated, coinciding with an increased market share of low efficiency models and the elimination of CEE tier 3-certified models for this product subcategory. Front-loading clothes washers are known to be, on average, more efficient than top-loading. Figure 4 shows that the Canadian MEPS is non-binding for the front-loading configuration, and most of the market is more efficient than ENERGY STAR. Moreover, a large number of units bunch at the CEE tier 3 level.

The bunching pattern is more evident for dishwashers (Figure 5). Once a new specification is announced (typically one or two years before the final version is in effect), models gradually move slightly above the new certification requirements. Shipments on the region in-between a previous and current ENERGY STAR level are practically reduced to zero after the specification revisions examined (versions 5.2 and 6.0).

ENERGY STAR for refrigerator-freezers was updated in April 2008 and September 2014. Figure 6 shows a clear pattern of bunching at the MEPS and ENERGY STAR levels. Furthermore, ENERGY STAR appears to be the main driver of efficiency in the market for this product category. I believe that manipulation of the efficiency level is more straightforward for this product category than for dishwashers and clothes washers for two reasons. First, certification requirements for dishwashers and clothes washers require effective use of water, in addition to the energy efficiency requirements.

Second, refrigerator-freezer ENERGY STAR requirements are a function of the adjusted volume of the appliance, which means that the design of the product may be optimized in order to facilitate certification.

I remind the reader that the refrigerator-freezer specification revision from 2014 coincides with updates to test procedures and minimum standards in the US for this product category. Refrigerator-freezer subtypes were redefined in the US to distinguish between products with added functionalities such as through-the-door ice dispensing and filtered water. During the development of the 2014 ENERGY STAR criteria, DOE published in a technical support document an approximate equivalency between the new measurement of energy use and the previous one, which is the same as in Canada. The choice of efficiency level for the reference line for the years 2014-2016 on Figure 6 is somewhat fuzzy since it is based on DOE's approximation. The histogram still shows clearly that bunching occurs above the ENERGY STAR threshold for the last three years, which suggests that measurement error – if it exists – is small.

I now proceed to the approach for calculating energy savings for the ENERGY STAR program. The approach mirrors closely the methodology utilized by a series of studies conducted by the Lawrence Berkeley National Laboratory (LBNL) for quantifying savings for ENERGY STAR-labeled products. With the support of the US EPA, researchers of the LBNL published program benefits for ENERGY STAR products for various calendar years (e.g. Sanchez *et al* 2008).

LBNL employs a bottom-up methodology where the unit energy savings for a given product category are estimated as the difference in energy consumption between a typical ENERGY STAR unit and a business as usual (BAU) benchmark unit. The BAU

represents an expected average efficiency of the products which would be available in a market without ENERGY STAR, and it is characterized by a mix of inefficient models and high efficiency models that would still exist in the absence of the program. To identify the BAU high efficiency models, the authors set BAU high efficiency equal to the market share of models that meet an upcoming ENERGY STAR requirement at the initial stage of the specification development. Next, unit energy savings are summed over annual sales and the process is aggregated over all product categories to yield the yearly program benefits in terms of energy saved.

Following the LBNL methodology, I start by deriving an attribution rate for each ENERGY STAR version for each product category. Let t_0 be the time of initial development for a new ENERGY STAR version with energy criterion h' , and let h be the criterion effective during t_0 . Let j correspond to models such that $h \leq e_j < h'$ and j' corresponds to models such that $h \leq e_{j'}$. Recall from equation (7) that s_α can identify the mass of models that move from an efficiency level near h to above h' between t_0 and the effective date of the new version. The attribution rate ϕ for the new ENERGY STAR version of a product category is simply the shipment-weighted calculation of s_α , i.e. the mass of *imported units* of type α models that move from around h to the efficiency threshold h' to meet the new certification requirements when they become effective.

$$\phi = \frac{\sum_j q_{jt_0}}{\sum_{j'} q_{j't_0}} - \frac{\sum_j q_{jt}}{\sum_{j'} q_{j't}}, \quad (7b)$$

where q_{jt} is the total shipments of class j at time t . In my dataset, t is measured in quarters.

For consistency in my analysis, the attribution rate of a product category considers the quarter t one year after the effective date of a particular ENERGY STAR specification and t_0 the quarter of the initial development for the criteria. The EPA's guidelines propose that a specification revision would be launched whenever 30% of the (unweighted) models in the market are ENERGY STAR-certified. Based on EPA's framework, we can expect that $\frac{\sum_j q_{jt_0}}{\sum_{j'} q_{j't_0}}$ would be around 70%, which would be an approximation of the upper bound for my estimated attribution rates. The actual upper bound may be slightly higher since my analysis focuses on the distribution of efficiency levels of shipments, which may differ from the unweighted distribution of models.

Once we obtain attribution rates for all specifications, the next step is determining the ENERGY STAR energy savings associated with a given product category. In order to be consistent with the LBNL methodology, the unit of time for the energy savings accounting is given in years rather than quarters. This decision is also influenced by the fact that annual energy savings is commonly used as an input to Canadian policymaking. We start by defining the unit energy savings (UES) associated with a new ENERGY STAR specification for a given product category:

$$UES_t = \phi(UEC_t^{non-ES} - UEC_t^{ES}) \quad (8)$$

where UEC_t^{non-ES} and UEC_t^{ES} are respectively the unit energy consumption of a typical non-ENERGY STAR model at time t and the unit energy consumption of a typical model that meets the new ENERGY STAR level. I use the energy consumption of a unit meeting the Canadian MEPS as a baseline value for UEC_t^{non-ES} . Likewise, UEC_t^{ES} is the expected energy consumption of a unit that barely meets the new ENERGY STAR

certification requirement. For refrigerator-freezers and clothes washers, the efficiency criteria are a function of product attributes (volume and tub capacity, respectively) and do not translate directly into the expected energy consumption. Therefore, I rely on equivalencies calculated in technical analyses performed by the DOE on ENERGY STAR and on non-ENERGY STAR energy consumption (DOE 2011, 2012 respectively).

It becomes clear from Equation (8) that the attribution rate ϕ determines the effectiveness of ENERGY STAR in transforming the market for energy efficiency. We have that ϕ close to zero implies ENERGY STAR has low effect on inducing firms to produce high efficiency models, and the UES for that product category is small. As ϕ increases, the program is more successful in yielding energy savings and possibly in inducing innovation in energy efficiency.

Next, I calculate annual energy savings (AES_t) by multiplying the number of ENERGY STAR units sold in each year with the corresponding UES_t . To calculate lifetime energy savings from a particular vintage (LES_t), I use a retirement function (see Appendix A) to accrue the savings from the surviving units only. Equations (9) and (10) below summarize the calculation of ENERGY STAR program benefits for a given product category:

$$AES_t = Q_t UES_t \quad (9)$$

$$LES_t = AES_t \sum_t^{t+L} \mu(t) \quad (10)$$

where Q_t is the number of ENERGY STAR units sold in year t ; L is the product expected lifetime; and, $\mu(t)$ is the assumed survival rate of the vintage on year t .

4. Results

Table 2 summarizes the attribution rates for each ENERGY STAR specification. The highest and lowest rates, on version 5 for clothes washer, can be explained by the fact that this specification was identical for top and front-loading configurations; almost all front-loading models already met the upcoming requirements when the version update was announced, and almost top-loading didn't.

I remark that the attribution rate of version 4 for refrigerator-freezers was derived from an unweighted distribution of models available in Canada, since shipment data was not available for the time of the version's initial development. For this reason, I caution that this estimate is likely less accurate than the others. One potential problem is that the NRCAN appliance directory may contain obsolete models which are no longer in the market but hasn't yet been removed from the database. Figure 6 also shows that models from the previous ENERGY STAR specification appear to have been removed from the market by 2009, despite the fact that the NRCAN models directory suggests the count of models that bunched around version 3 levels remained nearly constant since 2007. This potential measurement error is likely to bias my results, and the direction of the bias would be towards a lower estimate of the attribution rate.

An interesting question which arises at this point is: what inferences can we make from the ENERGY STAR specification revisions about manufacturers' decision to innovate and develop more efficient models? The question is warranted since results from Table 2 capture shipment decisions from manufacturers, which may not reflect trends in innovation and product development.

I examine the effect of ENERGY STAR specification revisions on the distribution of models offered over time. My estimation strategy is to test whether the distribution of the models available in the market is affected by updates in the ENERGY STAR criteria. Let once again h be an ENERGY STAR level at time t_0 and h' a specification revision that happens at $t_0 + i$, for some positive number of periods i . Let j correspond to models with efficiency e_j such that $h \leq e_j < h'$, and j' correspond to models with efficiency such that $e_{j'} \geq h'$. I opt for a non-parametric chi-square test to analyze whether the proportion of models j and j' is the same or changes over time.

The test statistic is a chi-square random variable χ^2 defined by the equation:

$$\chi^2 = \sum_{t=t_0}^{t_0+i} \sum_{k=j}^{j'} \frac{(O_{t,k} - E_{t,k})^2}{E_{t,k}} \quad (11)$$

where $O_{t,k}$ is the observed frequency of observations from period t and models k , and $E_{t,k}$ is the expected frequency of observations from period t and models k . Note that χ^2 equals zero only if $O_{t,k} = E_{t,k} \forall t, k$, i.e. only if the frequency of models of type j and j' is identical at time t_0 and $t_0 + i$. We now define the null (H_0) and alternative (H_a) hypothesis for the test:

H_0 : The proportion of j and j' are independent over time.

H_a : The proportion of j and j' are not independent over time.

The interpretation of the null hypothesis above is that the likelihood of a model of type j or j' being available in the market is the same for both periods. In contrast, rejecting the null hypothesis would imply that the period of time matters for the

likelihood of models of type j or j' being available in the market. Since the cardinality of groups t and k is two, this χ^2 test statistic has one degree of freedom. We reject the null hypothesis on the .1, .05, and .01 significance levels if the test statistic is greater than or equal to 2.71, 3.84, and 6.63 respectively.

For each ENERGY STAR revision, I first perform a chi-square test on the distribution of models j and j' offered at the time of initial development and the time corresponding to one year after the effective date of the specification. My goal is to determine whether the proportion of high efficiency models available after an ENERGY STAR revision is different in comparison to the proportion of high efficiency models at the time of announcement of the specification. Table 3 shows that, with the exception of ENERGY STAR v.7 for top-loading clothes washers, all chi-square test statistics on Table 3 are significant at the .01 significance level. This result indicates that the proportion of models j and j' available one year after the specification effective date is considerably different from the time of initial development. The tests are two-tailed and do not attempt to qualify whether the proportion over time favoured the high efficiency models j' or the decertified models j . However, the count of models presented in Table 3 shows a clear pattern: as models get decertified, they are no longer made available; meanwhile, more models meeting the new specification are introduced to the market.

Next, we examine whether the ENERGY STAR revision mechanism has a strong impact on the timing of manufacturers' decisions to upgrade the models on the efficiency dimension. Tables 4-11 present chi-square test results of comparing the models j and j' that were shipped into Canada in adjacent quarters. The impacts of the revision mechanism are most pronounced on dishwashers and refrigerator-freezers.

Table 4 shows that the differences in the proportion of dishwasher models before and after are only significant around the effective date of ENERGY STAR v.5. This appears not to be the case for clothes washers, since none of the chi-square tests yield significant results for differences in the proportion of models in adjacent periods. Possible reasons for this peculiar response could include difficulties in manipulating precisely the efficient level of models, or the presence of other initiatives, such as CEE certification, which diminish the value of ENERGY STAR. Last, results for refrigerator-freezer are significant and comparable to the outcome for dishwashers (see Table 11 for the ENERGY STAR v.5 output).

The results from the chi-square test seem to corroborate Houde and Spurlock's (2015) findings that manufacturers are strategic in the timing of new product line decisions. While I do not observe quality improvements in my dataset, I am able to verify that manufacturers move from previous to new efficiency certification levels shortly after the specification revision takes place.

Last, I present the calculation of estimated energy savings due to the ENERGY STAR specifications examined. Table 12 shows the lifetime energy savings for each product category. During their useful life, the products examined are estimated to save a total of approximately 25 petajoules due to ENERGY STAR, which is enough energy today to power roughly 225,000 Canadian homes for one year.

5. Discussion

This paper's analysis of the empirical distribution of appliance efficiency levels shows that manufacturers react to ENERGY STAR certification by providing more

efficient products. Through various revisions to the certification requirements, I derive ENERGY STAR's contribution to the provision of high efficiency products by estimating program attribution rates for the product categories examined. I also demonstrate that the impact of ENERGY STAR revisions is more pronounced for dishwashers and refrigerator-freezers than for clothes washers, perhaps because manufacturers are more capable of switching to more efficient models immediately after the effective dates.

In addition to the attribution rates, I also estimate program benefits in terms of energy saved due to ENERGY STAR. Even without accounting for the additional benefits of reduced greenhouse gas emissions from the energy sector, the estimated benefits are significant.

While evaluating ENERGY STAR program benefits is important, it is not sufficient to justify the value of the label. A possible extension for my work would be an evaluation of program costs for manufacturers and consumers. This extension would make possible a welfare analysis of ENERGY STAR in Canada, which, to the best of my knowledge, has not yet been conducted. In addition, I believe that the granularity of the dataset that I used could potentially allow for statistical analyses of the same product categories on other dimensions, such as overall product quality.

Despite its limitations, this paper contributes to the body of literature on ecolabels by finding new evidence of firms' strategic responses to certification. Moreover, this work provides further evidence of the benefits of energy efficiency ecolabels. The output presented has direct applications to Canadian policymaking on energy efficiency programs.

References

- Aguilar, F. X., & Vlosky, R. P. (2007). Consumer willingness to pay price premiums for environmentally certified wood products in the U.S. *Forest Policy and Economics*, 9(8), 1100-1112. doi:10.1016/j.forpol.2006.12.001
- Akerlof, G. A. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *The Quarterly Journal of Economics*, 84(3), 488. doi:10.2307/1879431
- Amacher, G. S., Koskela, E., & Ollikainen, M. (2004). Environmental quality competition and eco-labeling. *Journal of Environmental Economics and Management*, 47(2), 284-306. doi:10.1016/s0095-0696(03)00078-0
- Andreoni, J. (1990). Impure Altruism and Donations to Public Goods: A Theory of Warm-Glow Giving. *The Economic Journal*, 100(401), 464. doi:10.2307/2234133
- Bjorner, T., Hansen, L., & Russell, C. (2004). Environmental labeling and consumers' choice? – an empirical analysis of the effect of the Nordic Swan. *Journal of Environmental Economics and Management*, 47(3), 411-434. doi:10.1016/s0095-0696(03)00100-1
- Diamond, P. A., & Hausman, J. A. (1994). Contingent Valuation: Is Some Number Better than No Number? *Journal of Economic Perspectives*, 8(4), 45-64. doi:10.1257/jep.8.4.45
- DOE. (2011). Energy Conservation Program: Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers; Direct Final Rule. *Federal Register* 76FR57516, 57516-57612.
- DOE. (2012). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers; Direct Final Rule. *Federal Register* 77FR32308, 32308-32380.
- Eichholtz, P., Kok, N., & Quigley, J. M. (2010). Doing Well by Doing Good? Green Office Buildings. *American Economic Review*, 100(5), 2492-2509. doi:10.1257/aer.100.5.2492
- Gerarden, T., Newell, R. G., & Stavins, R. N. (2015). Deconstructing the Energy-Efficiency Gap: Conceptual Frameworks and Evidence. *American Economic Review*, 105(5), 183-186. doi:10.1257/aer.p20151012
- Houde, S. (2014a). How Consumers Respond to Environmental Certification and the Value of Energy Information (Working paper 20019). Retrieved from National Bureau of Economic Research website: <http://www.nber.org/papers/w20019>
- Houde, S. (2014b). Bunching with the Stars: How Firms Respond to Environmental Certification (Working Paper).

- Houde, S. (2014c). Belt and Suspenders and More: the Incremental Impact of Energy Efficiency Subsidies in the Presence of Existing Policy Instruments (Working Paper 20541). Retrieved from National Bureau of Economic Research website: <http://www.nber.org/papers/w20541>
- Houde, S., & Spurlock, C. A. (2015). Do Energy Efficiency Standards Improve Quality? Evidence from a Revealed Preference Approach. doi:10.2172/1235446
- Konar, S., & Cohen, M. A. (1997). Information As Regulation: The Effect of Community Right to Know Laws on Toxic Emissions. *Journal of Environmental Economics and Management*, 32(1), 109-124. doi:10.1006/jeem.1996.0955
- Kotchen, M. (2006). Green Markets and Private Provision of Public Goods. *Journal of Political Economy*, 114(4), 816-834. doi:10.1086/506337
- Nauc ler, T., & Enkvist, P. A. (2009). Pathways to a low-carbon economy: Version 2 of the global greenhouse gas abatement cost curve. McKinsey & Company, 192.
- NRCan. (2011). Energy Efficiency Trends in Canada: 1990-2009. Available at: oee.nrcan.gc.ca/statistics/publications
- Newell, R., & Siikam ki, J. (2013). Nudging Energy Efficiency Behavior: The Role of Information Labels (Working Paper 19224). Retrieved from National Bureau of Economic Research website: <http://www.nber.org/papers/w19224>
- Sallee, J. M., & Slemrod, J. (2012). Car notches: Strategic automaker responses to fuel economy policy. *Journal of Public Economics*, 96(11-12), 981-999. doi:10.1016/j.jpubeco.2012.06.005
- Sanchez, M. C., Brown, R. E., Webber, C., & Homan, G. K. (2008). Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program. *Energy Policy*, 36(6), 2098-2108. doi:10.1016/j.enpol.2008.02.021
- Tietenberg, T. (1998). Disclosure Strategies for Pollution control. *Environmental and Resource Economics*, 11(3-4), 587-602.
- Wallander, S. (2008). Price Impacts of the Energy Star Label – A Case of Redundant Information. Paper presented at 10th Occasional Workshop on Environmental and Resource Economics.
- Walls, M., Palmer, K. L., & Gerarden, T. (n.d.). Is Energy Efficiency Capitalized into Home Prices? Evidence from Three US Cities. SSRN Electronic Journal SSRN Journal. doi:10.2139/ssrn.2296032

Figures and Tables



Figure 1. ENERGY STAR Label

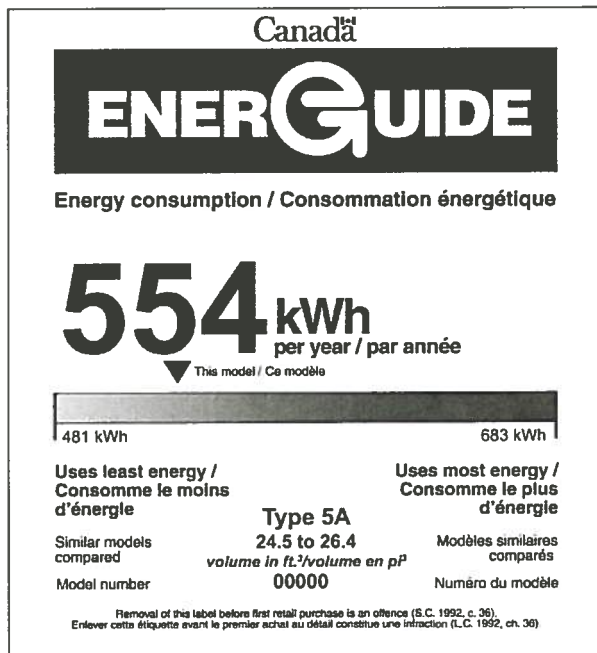


Figure 2. EnerGuide Tag

Top-Loading Clothes Washer Densities by Year

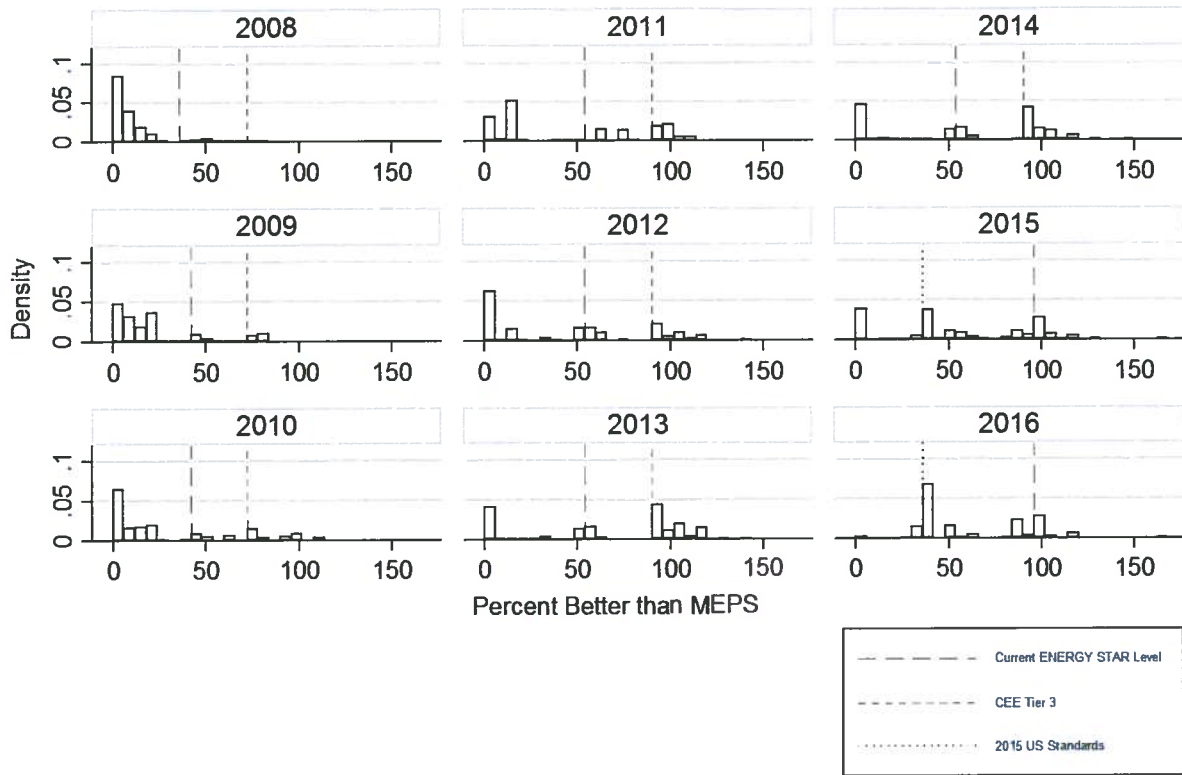


Figure 3. Distribution of Top-Loading Clothes Washer Shipments by Efficiency Levels

Front-Loading Clothes Washer Densities by Year

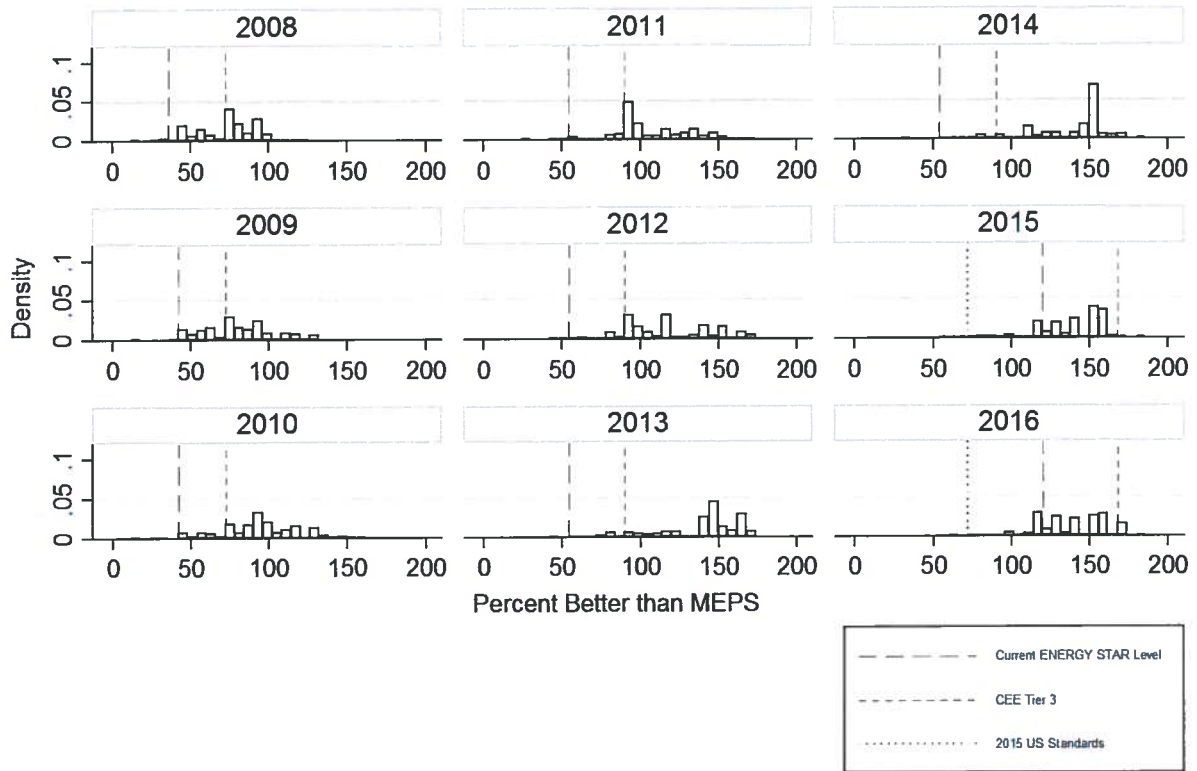


Figure 4. Distribution of Front-Loading Clothes Washer Shipments by Efficiency Levels

Standard Dishwasher Densities by Year

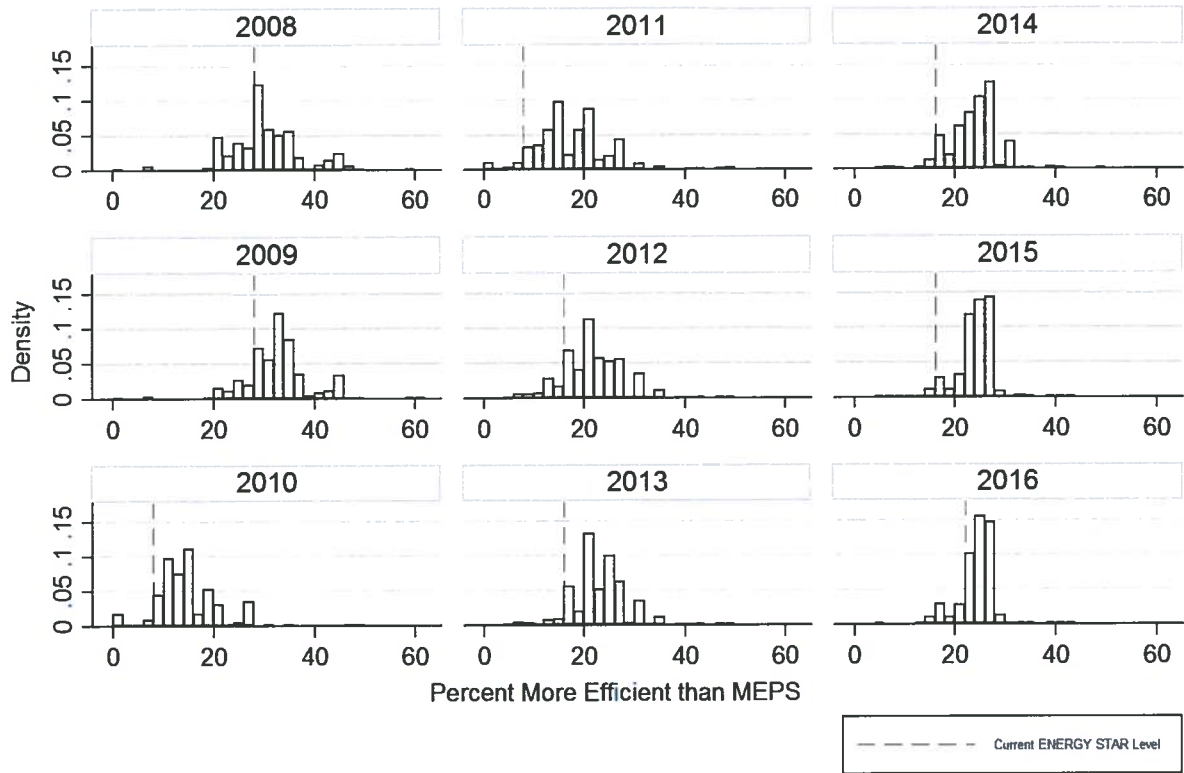


Figure 5. Distribution of Standard Dishwasher Shipments by Efficiency Levels

Refrigerator-Freezer Densities by Year

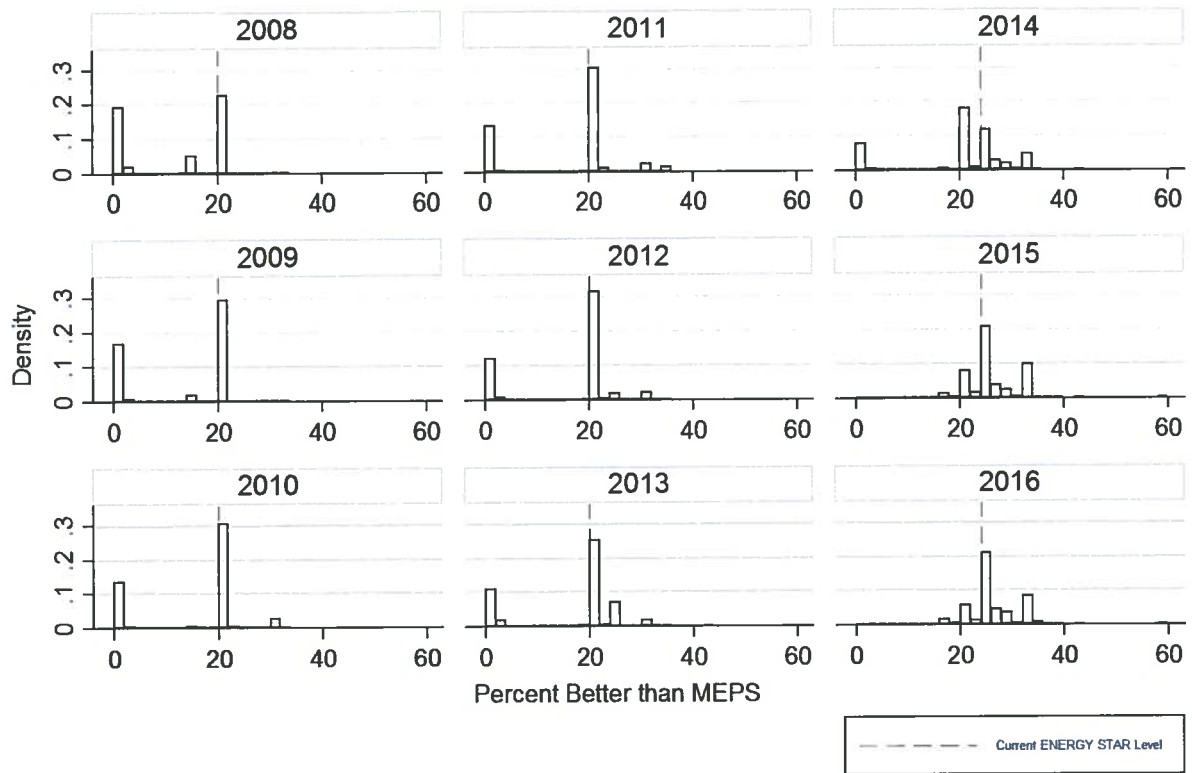


Figure 6. Distribution of Refrigerator-Freezer Shipments by Efficiency Levels

Table 1. Timeline of standards, test procedures and ENERGY STAR updates

Year	Event	Product Category	Announced Date	Effective Date
2008	ENERGY STAR Spec. Revision	Refrigerator-Freezers	April 27, 2007	April 28, 2008
2009	ENERGY STAR Spec. Revision*	Clothes Washers	January 9, 2008	July 1, 2009
	ENERGY STAR Spec. Revision	Dishwashers	August 15, 2008	August 11, 2009
2010	Canadian MEPS Update	Dishwashers	October 21, 2006	January 1, 2010
	US MEPS Update	Dishwashers	May 11, 2006	January 1, 2010
2011	ENERGY STAR Spec. Revision*	Clothes Washers	January 9, 2008	January 1, 2011
	US MEPS Update	Clothes Washers	-	January 1, 2011
2012	US Test Procedure Update	Dishwashers	December 2, 2012	December 17, 2012
2013	US MEPS Update	Dishwashers	May 30, 2012	May 30, 2013
2014	ENERGY STAR Spec. Revision	Refrigerator-Freezers	July 11, 2011	September 15, 2014
	US MEPS Update	Refrigerator-Freezers	September 27, 2010	September 15, 2014
	US Test Procedure Update	Refrigerator-Freezers	August 29, 2013	September 15, 2014
2015	ENERGY STAR Spec. Revision	Clothes Washers		March 7, 2015
	US MEPS Update	Clothes Washers	August 28, 2009	March 7, 2015
	US Test Procedure Update	Clothes Washers	March 7, 2012	March 7, 2015
2016	ENERGY STAR Spec. Revision	Dishwashers	December 12, 2013	January 29, 2016

*Two tiered specification. Phase 1 was effective on July 1, 2009 and phase 2 was effective on January 1, 2011.

Table 2. Attribution Rates for Various ENERGY STAR Specifications

Product Category	ENERGY STAR Version		Shipments†		Attribution Rate ³
			Before ¹	After ²	
Standard Dishwasher	Version 5	$j h \leq e_j < h'$	119743	5418	64%
		$j' h \leq e_{j'}$	169553	86358	
		Quotient	71%	6%	
	Version 6	$j h \leq e_j < h'$	41568	4667	38%
		$j' h \leq e_{j'}$	83056	37262	
		Quotient	50%	13%	
Front-Loading Clothes Washer	Version 5	$j h \leq e_j < h'$	21236	82	16%
		$j' h \leq e_{j'}$	131104	21108	
		Quotient	16%	0%	
	Version 7	$j h \leq e_j < h'$	27719	7212	51%
		$j' h \leq e_{j'}$	46183	80496	
		Quotient	60%	9%	
Top-Loading Clothes Washer	Version 5	$j h \leq e_j < h'$	3235	1	80%
		$j' h \leq e_{j'}$	4026	8786	
		Quotient	80%	0%	
	Version 7	$j h \leq e_j < h'$	14552	15758	22%
		$j' h \leq e_{j'}$	20119	31186	
		Quotient	72%	51%	
Refrigerator-Freezer ⁴	Version 4	$j h \leq e_j < h'$	1243	1153	36%
		$j' h \leq e_{j'}$	1371	2126	
		Quotient	91%	54%	
	Version 5	$j h \leq e_j < h'$	120806	96353	28%
		$j' h \leq e_{j'}$	139881	164881	
		Quotient	86%	58%	

1. Before corresponds to the time of announcement of an ENERGY STAR version.

2. After corresponds to exactly one year after the ENERGY STAR version is in effect.

3. Attribution rate is calculated as below.

$$\text{Attribution Rate} = \frac{\text{Shipments}_j^{\text{before}}}{\text{Shipments}_{j'}^{\text{before}}} - \frac{\text{Shipments}_j^{\text{after}}}{\text{Shipments}_{j'}^{\text{after}}}$$

4. Due to lack of shipment data in 2007, calculations for version 4 are based on the NRCAN directory of models available before (2007) and after (2009) the specification revision

† Shipments are aggregated quarterly.

Table 3. Chi-Square Test Results for Various ENERGY STAR Specifications

Product Category	ENERGY STAR Version		Models Offered [†]		Pearson's Chi-Square
			Before ¹	After ²	
Standard Dishwasher	Version 5	$j h \leq e_j < h'$	143	9	134.5914***
		$j' h' \leq e_{j'}$	139	224	(0.000)
	Version 6	$j h \leq e_j < h'$	105	18	55.4978***
		$j' h' \leq e_{j'}$	125	150	(0.000)
Front-Loading Clothes Washer	Version 5	$j h \leq e_j < h'$	24	3	11.7038***
		$j' h' \leq e_{j'}$	89	76	(0.001)
	Version 7	$j h \leq e_j < h'$	49	23	16.0638***
		$j' h' \leq e_{j'}$	31	55	(0.000)
Top-Loading Clothes Washer	Version 5	$j h \leq e_j < h'$	9	1	30.0444***
		$j' h' \leq e_{j'}$	1	29	(0.000)
	Version 7	$j h \leq e_j < h'$	14	7	0.4219
		$j' h' \leq e_{j'}$	31	22	(0.516)
Refrigerator-Freezer ³	Version 4	$j h \leq e_j < h'$	1243	1153	512.8038***
		$j' h' \leq e_{j'}$	128	973	(0.000)
	Version 5	$j h \leq e_j < h'$	292	200	62.6098***
		$j' h' \leq e_{j'}$	64	167	(0.000)

*** p<0.01. P-values in parenthesis.

1. Before corresponds to the time of announcement of an ENERGY STAR version.

2. After corresponds to exactly one year after the ENERGY STAR version is in effect.

3. Due to lack of shipment data in 2007, calculations for version 4 are based on the NRCAN directory of models available before (2007) and after (2009) the specification revision

† Unique models aggregated quarterly.

Table 4. Chi-Square Test: ENERGY STAR v.5 for Dishwashers

comparison groups	Before		After		Pearson's Chi-Square
	v.4 certified	v.5 certified	v.4 certified	v.5 certified	
2010.1 -- 2010.2	150	113	157	121	0.0172 (0.896)
2010.2 -- 2010.3	157	121	143	139	1.8710 (0.171)
2010.3 -- 2010.4	143	139	143	132	0.0929 (0.761)
2010.4 -- 2011.1	143	132	132	152	1.7040 (0.192)
2011.1 -- 2011.2	132	152	126	178	1.5095 (0.219)
2011.2 -- 2011.3	126	178	106	206	3.6625* (0.056)
2011.3 -- 2011.4	106	206	99	178	0.2016 (0.653)
2011.4 -- 2012.1	99	178	89	216	2.8564* (0.091)
2012.1 -- 2012.2	89	216	49	232	11.2015*** (0.001)
2012.2 -- 2012.3	49	232	34	214	1.3841 (0.239)
2012.3 -- 2012.4	34	214	34	219	0.0078 (0.929)
2012.4 -- 2013.1	34	219	24	219	1.5231 (0.217)
2013.1 -- 2013.2	24	219	16	239	2.1855 (0.139)
2013.2 -- 2013.3	16	239	17	228	0.0894 (0.765)
2013.3 -- 2013.4	17	228	9	224	2.1971 (0.138)
2013.4 -- 2014.1	9	224	11	230	0.1443 (0.704)
2014.1 -- 2014.2	11	230	11	227	0.0009 (0.976)
2014.2 -- 2014.3	11	227	10	224	0.0337 (0.854)
2014.3 -- 2014.4	10	224	7	224	0.5101 (0.475)

*** p<0.01, * p<0.1. P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.4 certified) and the number that meet the new specification (v.5 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in January 20, 2012.

Table 5. Chi-Square Test: ENERGY STAR v.6 for Dishwashers

comparison groups	Before		After		Pearson's Chi-Square
	v.5 certified	v.6 certified	v.5 certified	v.6 certified	
2014.1 -- 2014.2	105	125	93	134	1.0204 (0.312)
2014.2 -- 2014.3	93	134	84	140	0.5691 (0.451)
2014.3 -- 2014.4	84	140	82	142	0.383 (0.845)
2014.4 -- 2015.1	82	142	63	158	3.3229* (0.068)
2015.1 -- 2015.2	63	158	49	183	3.3177* (0.069)
2015.2 -- 2015.3	49	183	53	188	0.0530 (0.818)
2015.3 -- 2015.4	53	188	37	185	2.0924 (0.148)
2015.4 -- 2016.1	37	185	31	172	0.1537 (0.695)
2016.1 -- 2016.2	31	172	18	150	1.6650 (0.197)

* p<0.1. P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.5 certified) and the number that meet the new specification (v.6 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in January 29, 2016.

Table 6. Chi-Square Test: ENERGY STAR v.5 for Front-Loading Clothes Washers

comparison groups	Before		After		Pearson's Chi-Square
	v.4 certified	v.5 certified	v.4 certified	v.5 certified	
2008.2 -- 2008.3	24	89	19	98	0.9453 (0.398)
2008.3 -- 2008.4	19	98	20	92	0.1060 (0.861)
2008.4 -- 2009.1	20	92	18	91	0.0700 (0.859)
2009.1 -- 2009.2	18	91	22	113	0.0021 (1.000)
2009.2 -- 2009.3	22	113	18	116	0.4356 (0.608)
2009.3 -- 2009.4	18	116	18	109	0.0301 (1.000)
2009.4 -- 2010.1	18	109	17	119	0.1594 (0.719)
2010.1 -- 2010.2	17	119	12	121	0.8454 (0.433)
2010.2 -- 2010.3	12	121	11	121	0.0397 (1.000)
2010.3 -- 2010.4	11	121	12	131	0.0003 (1.000)
2010.4 -- 2011.1	12	131	7	111	0.5794 (0.483)
2011.1 -- 2011.2	7	111	5	112	0.3336 (0.768)
2011.2 -- 2011.3	5	112	8	108	0.7608 (0.409)
2011.3 -- 2011.4	8	108	4	98	0.9235 (0.387)
2011.4 -- 2012.1	4	98	3	76	0.0018 (1.000)

Fisher's Exact P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.4 certified) and the number that meet the new specification (v.5 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in January 01, 2011.

Table 7. Chi-Square Test: ENERGY STAR v.5 for Top-Loading Clothes Washers

comparison groups	Before		After		Pearson's Chi-Square
	v.4 certified	v.5 certified	v.4 certified	v.5 certified	
2008.2 -- 2008.3	9	1	9	5	2.0571 (0.341)
2008.3 -- 2008.4	9	5	9	8	0.4058 (0.717)
2008.4 -- 2009.1	9	8	8	7	0.0005 (1.000)
2009.1 -- 2009.2	8	7	9	6	0.1357 (1.000)
2009.2 -- 2009.3	9	6	10	11	0.5382 (0.516)
2009.3 -- 2009.4	10	11	8	8	0.0206 (1.000)
2009.4 -- 2010.1	8	8	9	9	0.0000 (1.000)
2010.1 -- 2010.2	9	9	8	16	1.1859 (0.348)
2010.2 -- 2010.3	8	16	6	24	1.2343 (0.353)
2010.3 -- 2010.4	6	24	5	30	0.3752 (0.742)
2010.4 -- 2011.1	5	30	4	33	0.1986 (0.732)
2011.1 -- 2011.2	4	33	2	33	0.6116 (0.675)
2011.2 -- 2011.3	2	33	1	35	0.3781 (0.614)
2011.3 -- 2011.4	1	35	1	38	0.0033 (1.000)
2011.4 -- 2012.1	1	38	1	29	0.0356 (1.000)

Fisher's Exact P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.4 certified) and the number that meet the new specification (v.5 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in January 01, 2011.

Table 8. Chi-Square Test: ENERGY STAR v.7 for Front-Loading Clothes Washers

comparison groups	Before		After		Pearson's Chi-Square
	v.5 certified	v.7 certified	v.5 certified	v.7 certified	
2012.3 -- 2012.4	49	31	49	32	0.0097 (0.922)
2012.4 -- 2013.1	49	32	39	39	1.7705 (0.183)
2013.1 -- 2013.2	39	39	32	52	2.3283 (0.127)
2013.2 -- 2013.3	32	52	27	46	0.0205 (0.886)
2013.3 -- 2013.4	27	46	24	48	0.2121 (0.645)
2013.4 -- 2014.1	24	48	33	54	0.3621 (0.547)
2014.1 -- 2014.2	33	54	37	65	0.0552 (0.814)
2014.2 -- 2014.3	37	65	30	64	0.4133 (0.520)
2014.3 -- 2014.4	30	64	22	65	0.9693 (0.325)
2014.4 -- 2015.1	22	65	32	59	2.0533 (0.152)
2015.1 -- 2015.2	32	59	22	57	1.0445 (0.307)
2015.2 -- 2015.3	22	57	20	53	0.0039 (0.950)
2015.3 -- 2015.4	20	53	17	54	0.2249 (0.635)
2015.4 -- 2016.1	17	54	23	55	0.5816 (0.446)

P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.5 certified) and the number that meet the new specification (v.7 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in March 07, 2015.

Table 9. Chi-Square Test: ENERGY STAR v.7 for Top-Loading Clothes Washers

comparison groups	Before		After		Pearson's Chi-Square
	v.5 certified	v.7 certified	v.5 certified	v.7 certified	
2012.3 -- 2012.4	14	31	14	29	0.0212 (0.884)
2012.4 -- 2013.1	14	29	14	36	0.2283 (0.633)
2013.1 -- 2013.2	14	36	13	35	0.0103 (0.919)
2013.2 -- 2013.3	13	35	12	48	0.7521 (0.386)
2013.3 -- 2013.4	12	48	14	38	0.7490 (0.387)
2013.4 -- 2014.1	14	38	10	39	0.5911 (0.442)
2014.1 -- 2014.2	10	39	15	39	0.7591 (0.384)
2014.2 -- 2014.3	15	39	12	31	0.0002 (0.989)
2014.3 -- 2014.4	12	31	10	30	0.0899 (0.764)
2014.4 -- 2015.1	10	30	11	31	0.0152 (0.902)
2015.1 -- 2015.2	11	31	14	28	0.5125 (0.474)
2015.2 -- 2015.3	14	28	13	27	0.0064 (0.936)
2015.3 -- 2015.4	13	27	9	24	0.2347 (0.628)
2015.4 -- 2016.1	9	24	7	22	0.0792 (0.778)

P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.5 certified) and the number that meet the new specification (v.7 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in March 07, 2015.

Table 10. Chi-Square Test: ENERGY STAR v.4 for Refrigerator-Freezers

comparison groups	Before		After		Pearson's Chi-Square
	v.3 certified	v.4 certified	v.3 certified	v.4 certified	
2007 -- 2008	1243	128	1515	630	198.5189*** (0.000)
2008 -- 2009	1515	630	1153	973	122.4279*** (0.000)

*** $p < 0.01$. P-values in parenthesis. Source: NRCan EnerGuide Directory. This table reports both the number of unique models that meet only the old specification (v.3 certified) and the number that meet the new specification (v.4 certified). The transition between ENERGY STAR specifications occurred in April 28, 2008.

Table 11. Chi-Square Test: ENERGY STAR v.5 for Refrigerator-Freezers

comparison groups	Before		After		Pearson's Chi-Square
	v.4 certified	v.5 certified	v.4 certified	v.5 certified	
2011.4 -- 2012.1	291	64	277	66	0.1696 (0.680)
2012.1 -- 2012.2	277	66	264	63	0.0001 (0.994)
2012.2 -- 2012.3	264	63	247	62	0.0642 (0.800)
2012.3 -- 2012.4	247	62	232	63	0.1533 (0.695)
2012.4 -- 2013.1	232	63	203	55	0.0001 (0.991)
2013.1 -- 2013.2	203	55	232	50	1.1069 (0.293)
2013.2 -- 2013.3	232	50	211	56	0.9260 (0.336)
2013.3 -- 2013.4	211	56	206	61	0.2736 (0.601)
2013.4 -- 2014.1	206	61	223	66	0.0000 (0.998)
2014.1 -- 2014.2	223	66	255	90	0.8952 (0.344)
2014.2 -- 2014.3	255	90	252	102	0.6520 (0.419)
2014.3 -- 2014.4	252	102	225	138	6.8164*** (0.009)
2014.4 -- 2015.1	225	138	212	134	0.0380 (0.846)
2015.1 -- 2015.2	212	134	193	159	2.9731* (0.085)
2015.2 -- 2015.3	193	159	200	167	0.0081 (0.928)

*** p<0.01, * P<0.1. P-values in parenthesis. This table reports both the number of unique models that meet only the old specification (v.4 certified) and the number that meet the new specification (v.5 certified). The bolded rows correspond to the transition between ENERGY STAR specifications, which occurs in September 15, 2014.

Table 12. Estimated Lifetime Energy Savings (LES) Due to ENERGY STAR

Product Category	ENERGY STAR Attribution version	Rate	UEC ^{non-ES}	UEC ^{ES}	UES	LES (petajoules)										
						2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	
Standard Dishwasher	Version 5	64%	355	295	38.4	0.00	0.00	0.00	0.00	1.15	1.19	1.20	1.21	0.00	4.97	
	Version 6	38%	355	270	32.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24		
Front-Loading	Version 5	16%	921	574	55.52	0.00	0.00	0.00	0.87	0.32	0.49	0.75	0.15	0.00	5.42	
Clothes Washers	Version 7	51%	921	473	228.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.81		
Top-Loading	Version 5	80%	921	574	277.6	0.00	0.00	0.00	1.53	0.68	1.45	2.32	0.38	0.00	6.64	
Clothes Washers	Version 7	22%	921	644	60.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.09		
Refrigerator-Freezer	Version 4	36%	521	417	37.44	0.81	1.18	1.45	1.25	0.73	0.37	0.42	0.00	0.00	7.95	
	Version 5	28%	521	350	47.88	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.97	0.28		

Notes: one petajoule is equal to 10^{15} joules, and is roughly the amount of energy required to power 9,000 Canadian households for one year (NRcan 2011). Sources for the unit energy consumption are identified in the references.

Appendix A

The US DOE characterizes the lifetime of the appliances examined in this paper by considering that the probability of failure over time follows a Weibull distribution. According to the DOE, the Weibull distribution is recommended for evaluating appliance lifespan because the flexibility in the choice of parameters allow for various distribution shapes that match each product category. With a Weibull distribution, the probability of failure on year t is:

$$f(t) = \frac{k}{\lambda} \left(\frac{t-L}{\lambda} \right)^{k-1} e^{-\left(\frac{t-L}{\lambda} \right)^k} \quad (11)$$

where:

L = location;

λ = scale; and,

k = shape.

The cumulative distribution for the Weibull is therefore:

$$F(t) = 1 - e^{-\left(\frac{t-L}{\lambda} \right)^k} \quad (12)$$

And the survival rate $\mu(t)$ of a vintage on year t is:

$$\mu(t) = 1 - F(t) \quad (13)$$

The table below specifies the Weibull parameters for each product category examined in this paper.

Table 13. Calibrated Parameters for Weibull Distributions

Product	λ (scale)	k (shape)	L (location)	Expected Lifetime
Clothes Washers	10.13	2.66	2	11.00
Dishwashers	16.29	2.31	1	15.43
Refrigerator-Freezers	13.91	1.68	5	17.37

The graphs below show side-by-side the probability of failure on year t and the survival rate of a vintage on the same year.

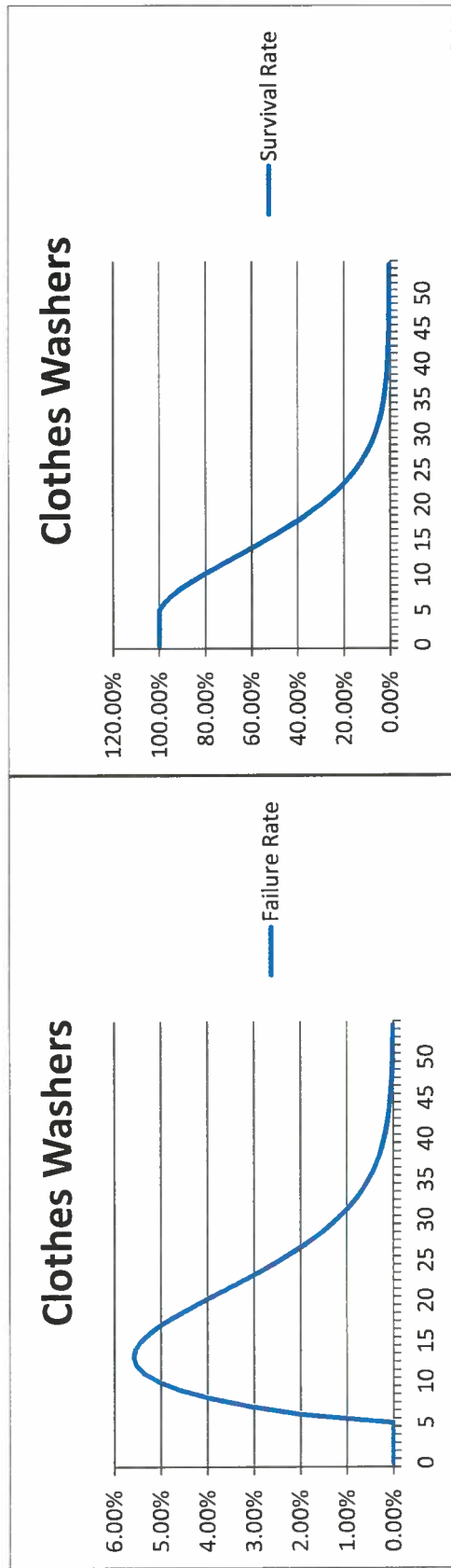


Figure 7. Failure and Survival Rates for Clothes Washers

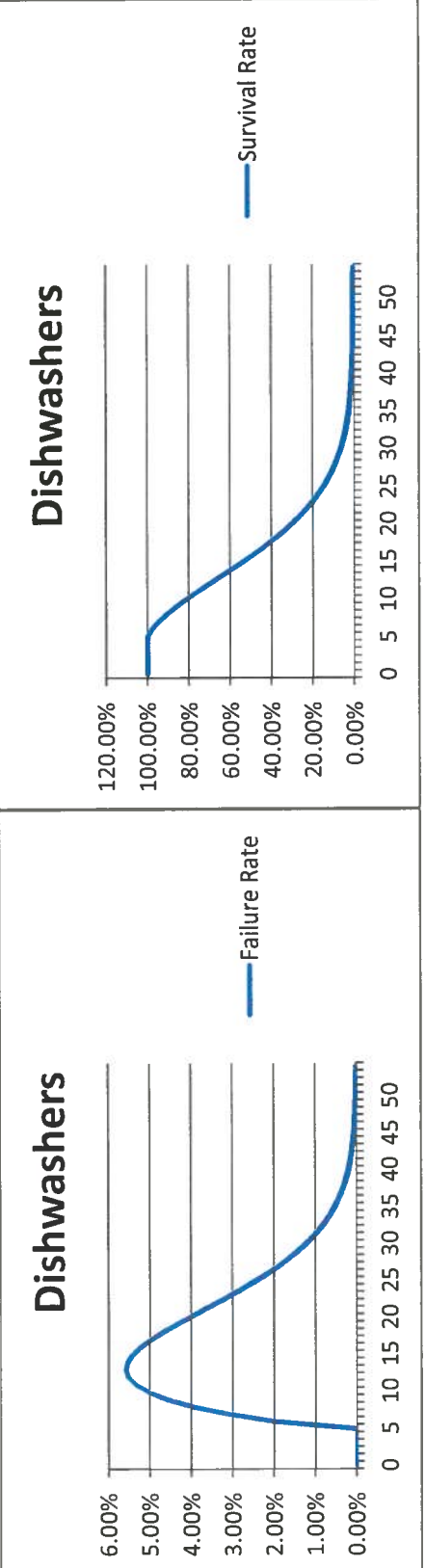


Figure 8. Failure and Survival Rates for Dishwashers

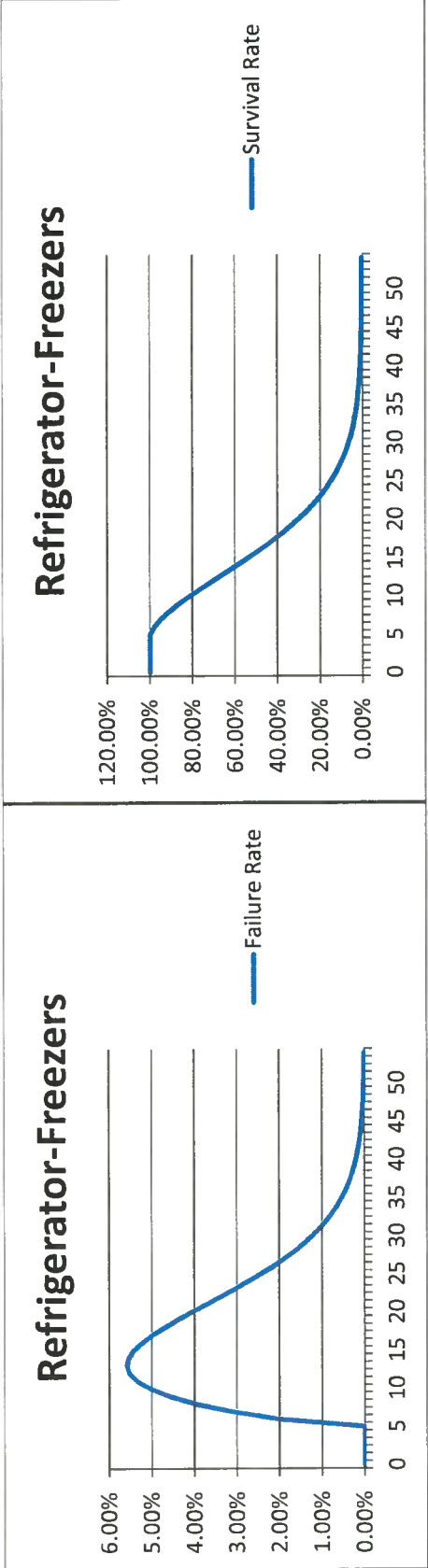


Figure 9. Failure and Survival Rates for Refrigerator-Freezers