Bunching with the Stars: How Firms Respond to Environmental Certification

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October 14, 2013

Abstract

This paper first shows that firms respond strategically to ENERGY STAR, a voluntary certification program for energy efficient products. In the US appliance market, firms offer products that bunch at the certification requirement, and charge a price premium for certified models. The second part of the paper performs a welfare analysis of the program with an emphasis on firms' strategic response. A model of imperfect competition where firms optimize energy efficiency and prices in response to environmental certification is estimated for the US refrigerator market. Policy simulations suggest that ENERGY STAR performs surprisingly well from the standpoint of economic efficiency, but most of the welfare gains come from firms' profits. Consumers would be better off in a market without certification. Firms' ability to alter the product mix plays a dominant role in determining the welfare effects.

JEL: L13, L15, L68, Q4, Q5.
Keywords: Certification, Product Differentiation, ENERGY STAR, Energy Efficiency.

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This paper is a revised version of a chapter of my PhD thesis. I would like to thank James Sweeney, Wesley Hartmann, and Jonathan Levin for their valuable input throughout this project. I would also like to thank James Sallee for suggestions and advice. Thank you also to Christopher Timmins, Lucas Davis, Anna Spurlock, David Rapson, Katrina Jessoe, Kyle Meng, and Antonio Bento, in addition of numerous seminar participants. Daniel Werner provided excellent research assistance for this project. Funding was in part provided by the Precourt Energy Efficiency Center at Stanford and the Social Sciences and Humanities Research Council of Canada.

1. Introduction

In an effort to push consumers toward environmentally friendly products, governmental entities, non-profit organizations, and trade associations have inundated marketplaces with environmental certifications and ecolabels. When information about product attributes is hard to collect, process, or simply shrouded, certifications are justified if they correct informational market failures. In practice, however, ecolabels tend to provide a limited amount of hard information, and resemble simple branding strategies. Even so, they can improve social welfare if they impact choices, and ultimately lead to reductions in negative externalities.

Complications arise when firms strategically respond to certification. If firms distort product design and prices to take advantage of a certification, this may have uncertain welfare effects. When informational problems, externalities, and firm's behavior interact, it is then unclear if environmental certification is a desirable policy tool. This paper contributes to this debate, and conducts a welfare analysis of the ENERGY STAR program, perhaps the most well-known environmental certification in the US. The emphasis is on the role of firms' strategic response, and on how the certification distorts product line and pricing decisions.

The analysis proceeds in three steps. Using data from the US appliance market, I show that ENERGY STAR influences the provision of energy efficiency and prices. Firms tend to offer products that bunch at the certification requirement, and charge a price premium on certified models. I then rationalize the stylized facts with a model of imperfect competition, and carry out a structural estimation with data from the US refrigerator market. This allows me to simulate the market with and without certification, demonstrate the distortions at play in the market, and quantify the welfare effects associated with ENERGY STAR.

I find that ENERGY STAR leads to energy savings, and brings significant welfare gains of the order of $889 million annually for the US refrigerator market alone. This corresponds to an average of $98 per refrigerator sold. The bulk of the gains comes from firms' profits. Firms benefit from the certification because some consumers have a high willingness to pay for the label, which allows firms to differentiate products in the energy dimension and maintain higher markups. Consumers, on the other hand, would be better off in a market without certification. When ENERGY STAR is not in effect, firms offer products that just meet the federal minimum energy efficiency standards, with a few products exceeding the minimum standards. Products are therefore less differentiated, which increases competition, and reduces markups. Consumers are simply better off with cheaper but less energy efficient refrigerators.

Although ENERGY STAR is one of the main policies used in the US to manage energy demand, this paper is the first attempt to conduct a welfare analysis of the program. Prior work on ENERGY STAR has focused on estimating how consumers value the certification (Houde 2012; Newell and Siikamäki 2013; Eichholtz, Kok, and Quigley 2010; Walls, Palmer, and Gerarden 2013; Ward, Clark, Jensen, Yen, and Russell 2011). These studies show that consumers' willingness to pay for ENERGY STAR is large, and even exceeds the monetary value of the energy savings associated with certified products. This suggests that consumers may have biased perceptions of the meaning of the certification, and/or value energy savings beyond purely financial motives. The US Environmental Protection Agency (EPA) has also conducted periodic assessments of the program with an emphasis on various marketing metrics. In general, ENERGY STAR is believed to be an effective branding strategy, and thus successful in favoring the adoption of energy efficient products. The main contribution of this paper is to develop an economic framework that shows that if ENERGY STAR acts as a brand and biases the valuation of energy efficiency, it may have unintended consequences. Firms can use second price discrimination to exploit consumers' biases, and extract more consumer surplus.

This paper complements a large body of work on instrument choice for environmental policy. My work is closely related to recent studies that have compared standards to market-based instruments in the car market accounting for firms' strategic response (Holland, Hughes, and Knittel 2009; Klier and Linn 2012; Jacobsen 2013; Whitefoot, Fowlie, and Skerlos 2011; Fischer 2010). The general consensus from these studies is that mandatory minimum standards reduce profits and are dominated by market-based instruments. The present paper focuses on a different market, but more importantly on a different use of standards. The fact that ENERGY STAR acts as a voluntary standard and induces innovation beyond a minimum standard is an important determinant of the welfare gains.

The conclusions reached in this paper have broader implications for the design and evaluation of certification programs, nudges, and other information-based policies. In markets where consumers are prone to making sub-optimal decisions because product information is too complex or missing, labeling schemes have the potential to alleviate these problems. These policies are usually analyzed with a focus on consumer behaviors. My results suggest that leaving firms' strategic response out of the analysis may not only underestimate the size of the welfare effects, but also the sign.

This paper also contributes to the estimation of games of strategic interactions with discrete-continuous strategy space. In the present context, product line decisions with respect to energy efficiency have a discrete component because of the binary nature of the ENERGY STAR certification. This complicates the identification and estimation of firms' costs. I propose an estimator based on profit inequalities (Pakes 2010; Pakes, Porter, Ho, and Ishii 2011) to recover the primitives of the cost function. Prior applications of moment inequalities in industrial organization have been primarily for models of strategic entry (Holmes 2011; Ellickson, Houghton, and Timmins 2013) and auctions (Fox and Bajari 2013). The present paper proposes a novel, but natural application of such method. Using proprietary data on costs, I show that the structural estimator performs well.

The remainder of the paper is organized as follows. The next section discusses the justifications for product certification in the appliance market. Section 3 presents stylized facts that firms respond to the ENERGY STAR certification. Sections 4-6 develop and estimate an oligopoly model of the US refrigerator market. Policy analysis follows in Section 7.

2. Certification and the Appliance Market

The ENERGY STAR program was first established in 1992, and is managed by the US EPA and the Department of Energy (DOE). As of 2013, more than sixty categories of products are covered by the program. For most appliances, the certification requirement is binary[1] and defined relative to the federal mandatory minimum energy efficiency standard. Products that meet or exceed the requirement are certified and have the right to be marketed with the ENERGY STAR label (Figure 1(a)). The label consists of a simple brand logo that does not contain technical information. In the US appliance market, technical information is, however, also provided to consumers by the EnergyGuide label, which is managed by the Federal Trade Commission (Figure 1(b)). Unlike ENERGY STAR, EnergyGuide is a mandatory labeling program, and provides detailed information about energy operating costs. For the appliance categories covered by EnergyGuide, all appliance models offered in the marketplace must display the label prominently, but only the most energy efficient products have the ENERGY STAR label.

Note that ENERGY STAR is an information program, but in some regions, utilities and local governments offer small rebates to encourage the adoption of certified products.

Historically, ENERGY STAR has been justified by two interacting market failures: consumers' undervaluation of energy efficiency and negative externalities associated with energy use. In the appliance market, there is a third market failure, which although overlooked, can also justify a

[1]Since 2012, the EPA has been experimenting with a certification with multiple tiers. This paper focuses on the binary version of ENERGY STAR.

program such as ENERGY STAR. Imperfect competition, and more particularly the extent to which firms distort the provision of energy efficiency, is also a rationale for policy intervention. As I will show, a certification program is an imperfect way to correct for these distortions, but can still help improve the market outcomes.

2.1. Market Structure of the US Appliance Market

There are several reasons to believe that imperfect competition could be at play in the appliance market. In the last decades, there have been notable mergers and acquisitions, which led to an increase in market concentration. The US market for white goods such as refrigerators, clothes washers, and dishwashers are now dominated by three manufacturers: Electrolux, Whirlpool, and General Electric. For the refrigerator market alone, these three manufacturers had about 85% of the market shares in 2008 (Table 1).

A particular institutional feature of the US appliance market is that manufacturers compete under various brand names, and some brands, such as Kenmore, are not owned by a particular manufacturer. Kenmore products are then produced by competing manufacturers, which is believed to be a feature that limits manufacturers' market power. The distribution of products across brands, however, is still concentrated (Table 1). Brand managers themselves should then be able to exercise market power.

3. Stylized Facts

In oligopolistic markets, firms differentiate their products and charge prices above marginal costs. This section provides evidence that ENERGY STAR facilitates both: firms tend to offer appliance models that just meet the certification requirement, and charge a price premium on products with the ENERGY STAR label.

3.1. Product Lines

The data for this analysis were collected from the websites of the main appliance retailers operating in the US: Best Buy, Lowes, and Sears. I extracted attribute information from the product web pages of all the appliance models offered in a subset of appliance categories. The data were collected between September and December 2012, and thus provide a snapshot of the US appliance market at this particular point in time.[2]

Figure 2 shows the empirical distribution of products in terms of energy efficiency for four appliance categories: refrigerator, dishwasher, clothes washer, and room air conditioner. Energy efficiency is measured as the percentage difference between the electricity consumption of each product offered and the federal minimum standard associated with this product. For all these appliances, the ENERGY STAR certification requirement is set relative to the minimum standard, which is identified by the vertical line.

For air conditioners and refrigerators, ENERGY STAR has a clear effect; products bunch almost exclusively at the minimum standard and the certification requirement. For dishwashers, products tend to bunch at ENERGY STAR, but this is not as pronounced. As of December 2012, all clothes washers offered by the main retailers met the ENERGY STAR criterion, and several products exceeded the threshold by a large margin. Sallee (2011) provides similar evidence for earlier years, and shows that voluntary certification has a similar effect in the building market.

Looking at the dynamics in the choice set, the data also suggest that manufacturers have the ability to adjust to a revision in certification requirement quickly. For instance, Figure 3 shows how product lines evolved from 1995 to 2009 for one particular type of appliance: the full-size refrigerator. The ENERGY STAR program was introduced in this market in 1997, and the certification requirement was revised in 2001, 2004, and 2008. Interestingly, in the first years of the program, the certification appears to have few effects on the market. The empirical distributions of energy efficiency are similar in 1995 and 1999, with most products bunching at the minimum standard, and some products exceeding the minimum by 5% to 20%. This suggests that in the initial years, firms did not believe that consumers were valuing the certification highly. This changed overtime. Following the two revisions in 2004 and 2008, firms responded not only by offering new models that met the revised requirement within a year, but also by discontinuing models that were decertified.

[2]For some appliances, I complemented the data with various publicly available datasets maintained by the California Energy Commission (CEC), the Federal Trade Commission (FTC), and the EPA. These various datasets allowed me to reconstruct the energy efficiency measure used by the Department of Energy and the EPA to determine the federal minimum energy efficiency standards and the ENERGY STAR requirements.

3.2. **Pricing**

If some consumers value ENERGY STAR and products can be differentiated, firms can set prices above marginal costs and extract part of the consumer surplus associated with ENERGY STAR. I next show that this is the case; firms charge different prices for the exact same refrigerator models with and without the ENERGY STAR label. I exploit two events that occurred in the refrigerator market that led to the decertification of refrigerator models. As mentioned above, in 2008 the EPA revised the certification requirement for full-size refrigerators. A large number of products then lost their ENERGY STAR certification. In January 2010, a similar event occurred. The EPA found that a number of ENERGY STAR refrigerator models (21) had undergone problematic testing procedures. As a result, their electricity consumption was underestimated. The EPA concluded that these refrigerator models were not meeting the ENERGY STAR requirement, and issued a public statement that they would be decertified.

The data used for this analysis are the weekly prices of all refrigerator models sold at a major US appliance retailer. For each refrigerator two prices are observed, the manufacturer's suggested retail price (MSRP) and the promotional price. The data cover the period January 2007 to December 2011.

I estimate the impact of the change in decertification using a difference-in-difference estimator. For the 2008 decertification, I use refrigerator models that were never certified ENERGY STAR or met the new certification as a counterfactual. For the 2010 decertification, I restrict the sample to refrigerator models that were certified as of January 2010. In my sample, 16 of these refrigerator models lost their certification because of the problematic testing procedure. Models that were certified ENERGY STAR and did not lose their certification serve as counterfactuals.

The effect of decertification is estimated with the following model:

$$log(P_{jt}) = \rho ESTAR_{jt} + \alpha_t + \gamma_j + \epsilon_{jt} \tag{1}$$

where α_t and γ_j are week and product fixed effects, respectively. The dependant variable is the log of the weekly price. The estimation is performed using the MSRP or the promotional price. $ESTAR_{jt}$ is a dummy variable that takes a value one if product j is certified in week t, and zero otherwise. The dummy variable $ESTAR_{jt}$ only varies for products that lose their certification in 2008 or 2010. The dummy γ_j captures all time-invariant product attributes specific to each refrigerator model. The coefficient ρ is then the quantity of interest, and estimates the impact of removing the ENERGY STAR label on a given refrigerator model.

2008 Decertification. I estimate the effect of the 2008 decertification with data from January 2007 to December 2009. During that period, there were 2,337 different refrigerator models sold at the retailer, and 1,347 lost their ENERGY STAR certification in April 2008.

Figure 4 (panels a and b) provides graphical evidence of the impact of decertification on prices. The average normalized prices (MSRP and promotional) for three efficiency classes are shown: models that lost their certification, models that were not certified ENERGY STAR as of January 1 2007, and models that did not lose their certification following the revision. Normalized prices are computed by dividing the price of each refrigerator model by its average price. Figure 4 plots the mean and the standard errors of a flexible regression spline fitted on the normalized price, and allows for a discontinuity in the last week of April 2008.

For both the MSRP and the promotional price, there is no clear evidence that the prices of decertified models changed around the time of the revision. In the post-revision period, however, we observe that the MSRPs of non-ENERGY STAR models, and ENERGY STAR models that remained certified, have a strong upward trend cumulating with a large price increase in the first week of the year 2009. The prices of decertified ENERGY STAR models have a similar trend, but it is much less pronounced. In relative terms, decertified models thus became less expensive in the post-revision period. The trends for promotional prices are similar, although they are subject to larger weekly variations.

The difference-in-difference estimator provides a valid estimate of the effect of decertification, if we believe that decertified models would have been subject to a similar trend than non-decertified models in the post-revision period had the decertification not occurred. This is a strong assumption. There are a number of factors that could explain the large increase in prices in 2008. I conjecture that the Great Recession might have played a role. Firms anticipating lower demand for durables might have increased prices, which will be consistent with theories of countercyclical markups.

Table 2 presents the estimates. Consistent with the graphical evidence, they both suggest that the decertification led to a small but significant relative price decline.[3] The reduction is 4.6% for MSRP, and 2.0% for promotional prices.

2010 Decertification. The 2010 decertification was a smaller event, but it offers a clearer picture. Figure 4 (panels c and d) shows the average normalized MSRP and promotional prices for refrigerator models that lost their certification, and for models that were certified ENERGY STAR

[3]A positive coefficient for ρ means that prices are higher when products are certified $ESTAR = 1$.

as of January 1, 2009. The figure clearly shows that firms responded by decreasing the prices of decertified models. The difference-in-difference estimator suggests that the MSRP decreased by 4.5%, and the promotional prices decreased by 1.2%.

One caveat with the interpretation of the 2010 event is that decertified models not only lost the ENERGY STAR label, but were also required to have a new EnergyGuide label with accurate energy information. The change in labeling is then confounded with a change in technical energy information. The change in prices captures both consumers' valuation of ENERGY STAR and energy costs. For the present purpose, these estimates are still relevant. It shows that in this market firms have the ability to charge prices above marginal costs, and rely on energy related information to set higher markups.

Altogether, these stylized facts suggest that firms operating in the appliance market are aware of the ENERGY STAR certification, believe that consumers value it, and optimize their product lines and prices consequently. Two necessary conditions to explain bunching at the minimum and ENERGY STAR standards and price premium on certified products is that firms have the ability to exercise some market power, and consumer preferences for energy efficiency are heterogeneous. I next present a model of the appliance market that incorporates these features.

4. Model

I characterize the appliance market with a static model of imperfect competition where firms strategically determine the energy efficiency level and the price of each product they offer. The model aims to represent a medium-run equilibrium where firms adjust to a policy change within 12 to 18 months. The decisions to enter and exit the market, and to determine the size and non-energy attributes of product lines are taken as given. My approach closely follows Jacobsen (2013), Klier and Linn (2012), and Whitefoot, Fowlie, and Skerlos (2011), among others, who model car manufacturers' product design decisions in response to fuel economy standards. The present model, however, has a different purpose and looks at the role of voluntary standards. Moreover, a number features specific to the appliance market motivate the following modeling assumptions.

4.1. Assumptions

Assumption 1: Firms Are Brand Managers. An important feature of the appliance market is that manufacturers offer similar products under different brand names. To circumvent the difficulties associated with modeling the manufacturers' decision to rebrand products (e.g., product cannibalization and double marginalization), I will focus on modeling the behavior of brand managers. I will assume that each brand manager represents a firm that maximizes the profits of his own brand. In this context, a product line decision consists of acquiring appliance models through procurement contracts with manufacturers; and brand managers' product unit costs are simply the prices they pay to manufacturers (wholesale prices). The model endogenizes markups set by brand managers, but not the manufacturers' markups.

Assumption 2: Cost of Providing Energy Efficiency Is Separable. A second important feature of the appliance market is that within a relatively short time firms can change the energy efficiency level of their products, with little impact on their overall design. This has been demonstrated during the various revisions in the ENERGY STAR standard; manufacturers systematically managed to offer new products that were more energy efficient, but were otherwise similar to previous generations.[4] I take this as evidence that the cost of providing energy efficiency is separable from the cost of providing other attributes. I will further assume that the unit costs faced by brand managers, i.e., the wholesale prices, reflect this assumption.

4.2. A Static Multi-Product Oligopoly Model

Consider that there are K brands, and brand manager k offers J_k appliance models. Brand manager k maximizes profits by choosing the energy efficient levels, the vector $f_k = \{f_{k1}, ..., f_{kJ_k}\}$, and the prices, the vector $p_k = \{p_{k1}, ..., p_{kJ_k}\}$, of his J_k models, taking the actions of rival firms as given. Firms face a population of heterogeneous consumers in which the demand for each product is $Q_{kj}(f, p|\theta, \tau, \psi)$, and depend on all energy efficiency levels and prices ($f = \{f_1, ..., f_K\}$ and $p = \{p_1, ..., p_K\}$). Consumer preferences for energy efficiency and ENERGY STAR are captured by three parameters. The parameter θ captures the sensitivity to future energy costs. Note that firms' choice of energy efficiency levels translate in how much energy each product will consume. Consumers do not value energy efficiency per se, but the energy operating costs they will pay. The parameters τ and ψ capture the valuation of the ENERGY STAR label and sensitivity to ENERGY STAR rebates, respectively. Consumers, at least some, may value the ENERGY STAR label itself because of bias in the perception of quality, warm glow preferences, and/or social preferences that

[4] Interestingly, when the EPA announced in April 2007 that the ENERGY STAR standard for refrigerators would be revised in April 2008, all but one manufacturer notified the EPA that they would not be able to offer new refrigerator models on time to meet the revised standard. Ultimately, most manufacturers were, however, able to offer new models meeting the 2008 ENERGY STAR standard within a year of the date that the EPA made the announcement.

arise when they purchase certified products (Houde 2012). All these behavioral effects,[5] combined with the effects of rebates, contribute to create a discontinuity in the valuation of energy efficiency at the ENERGY STAR requirement (noted f^{ES}).

The problem of the brand manager k consists in solving:

$$\max_{\substack{f_k=\{f_{k1},\dots,f_{kJ_k}\},\\ p_k=\{p_{k1},\dots,p_{kJ_k}\}}} = \sum_{j=1}^{J_k} (p_{kj} - c_{kj}(f_{kj})) \cdot Q_{kj}(f, p|\theta, \tau, \psi)$$

$$\text{s.t.} f \geq \underline{\text{f}}$$

where $c_{kj}(f_{kj})$ is the unit cost of model j offered by brand k, and $\underline{\text{f}}$ is the minimum energy efficiency standard that each product must meet.

The first order conditions for firm k are given by:

$$Q_{kl}(f^*, p^*|\theta, \tau, \psi) + \sum_{j=1}^{J_k} (p^*_{kj} - c_{kj}(f^*_{kj})) \cdot \frac{\partial Q_{kj}(f^*, p^*|\theta, \tau, \psi)}{\partial p^*_{kl}} = 0, \tag{2}$$

$$\begin{aligned} &\mathbf{1}\{\pi(f_{kl}, f^*_{k,-l}, p^*_k) > \pi(f^{ES}_{kl}, f^*_{k,-l}, p^*_k)|\forall f_{kl}\}\times \\ &\left[Q_{kl}(f^*, p^*|\theta, \tau, \psi) \frac{dc_{kl}(f^*_{kl})}{df_{kl}} - \sum_{j=1}^{J_k} (p^*_{kj} - c_{kj}(f^*_{kj})) \cdot \frac{\partial Q_{kj}(f^*, p^*|\theta, \tau, \psi)}{\partial f_{kl}} = 0 \right], \end{aligned} \tag{3}$$

$$\begin{aligned} &\mathbf{1}\{\pi(f_{kl}, f^*_{k,-l}, p^*_k) \leq \pi(f^{ES}, f^*_{k,-l}, p^*_k)|\forall f_{kl}\}\times \\ &\left[f^*_{kl} = f^{ES} \right], \\ &\text{for all } l \in J_k \text{ and } k \end{aligned} \tag{4}$$

$$\begin{aligned} &f_{kl} \geq \underline{\text{f}} \\ &\text{for all } l \in J_k \text{ and } k \end{aligned} \tag{5}$$

The vectors f^* and p^* correspond to the Nash equilibrium that solves the system of $3 \times (J_1 + J_2 + ...J_K)$ equations. In the second and third conditions the indicator function arises because the demand function is not continuous at f^{ES}; the derivative of the profits with respect to energy efficiency level f_{kl} is then not defined at this point. The discontinuity at the certification

[5] In the empirical part of the paper, I will be agnostic on the causes of the discontinuity, but I will exploit variation in labeling to estimate the size of the behavioral parameter τ. In what follows, simply assume that consumers value the ENERGY STAR label itself.

requirement implies that it may not be optimal to equate the marginal cost of providing energy efficiency with the marginal benefit. In the presence of ENERGY STAR, firms' strategies then become a discrete-continuous choice where firms decide whether or not to bunch at the certification requirement and which price to set. The existence and uniqueness of an equilibrium in this game are not guaranteed.

In the absence of certification, we have $\tau = 0$ and $\psi = 0$, and the first-order conditions with respect to energy efficiency simplify to

$$Q_{kl}(f^*, p^*|\theta)\frac{dc_{kl}(f^*_{kl})}{df_{kl}} - \sum_{j=1}^{J_k}(p^*_{kj} - c_{kj}(f^*_{kj})) \cdot \frac{\partial Q_{kj}(f^*, p^*|\theta)}{\partial f_{kl}} = 0. \tag{6}$$

This becomes a standard model of oligopolistic competition where firms engage in second degree price discrimination by adjusting one dimension of quality. The implications in the present context, is that when ENERGY STAR is not in effect firms will still distort the provision of energy efficiency. An environmental certification can then play a role in increasing the provision of energy efficiency. This will contribute to reduce environmental externalities, and be at the source of welfare gains. However, a certification may facilitate the exercise of market power, which will lead to higher prices and reduces consumer surplus. The welfare effects are then unclear.

5. Estimation

The focus of this section is on the cost estimation, and especially the identification of the marginal cost of providing energy efficiency. The demand estimation was developed in a companion paper (Houde 2012), and is outlined below.

5.1. Data

The demand estimation is carried with transaction level data of the US refrigerator market for the year 2008. The data were provided by an appliance retailer with non-marginal market shares in the US appliance market. For each transaction, I observe the refrigerator model purchased, the price and taxes paid, attribute information, and the location of the store. For a large subset of transactions, I also observe demographic information. Only transactions that can be imputed to a household are considered. The MSRP and promotional prices are provided for each transaction, which allows me to construct price time series that are model and region specific.

The retailer also provided attribute information for all refrigerator models that were offered at the store between 2007 and 2011. In addition of product characteristics, I observe the manufacturer's suggested retail price (MSRP) and the wholesale price for all these refrigerator models.

The retailer data are complemented with data on electricity prices (Energy Information Administration, Form EIA-861), and rebates (DSIRE database). Data from the Federal Trade Commission are also used to determine which refrigerator models were on the market during the period 2007-2011.

5.2. **Cost Estimation**

The goal of the cost estimation is to identify the unit cost of each product offered and the marginal cost of providing energy efficiency. For the estimation, I make a functional form assumption and define the unit cost of product l offered by brand manager k as follows:

$$c(f_{kl}) = e^{(\alpha_{kl}+\phi f_{kl})} \tag{7}$$

I estimate α_{kl}, a constant specific to each product, and the parameter ϕ, which determines how the unit cost varies as a function of energy efficiency. Energy efficiency is defined as the inverse of energy consumption. This is a convenient modeling assumption that allows me to link supply and demand; the energy costs faced by consumers are simply the inverse of the energy efficiency levels set by firms multiplied by the energy price. Under this functional form, the costs are increasing and convex with respect to energy efficiency if $\phi > 0$.

I also assume that there are five brand managers operating in the US refrigerator market: the four main brands, and a generic brand that includes all other brands. Brand managers compete by placing their products at appliance stores. To reduce the dimensionality of the problem, I model the game for only one appliance store, which is representative of the US refrigerator market. The choice set is fixed at 78, and the number of refrigerators offered by each firm is held constant. The size of the choice set corresponds approximately to the number of models offered in a store in my sample.[6] To ensure that the choice set is representative of the US market, the distribution of the 78 products in terms of brand, style, size, and energy efficiency was selected to fit the distribution

[6]In my sample, the average number of refrigerator models offered by a store is 133 (Table 3). I set the size of the choice set to 78 for computational reasons. Although I was able to solve the model for larger choice sets, the simulation results were more robust and converged faster with smaller choice sets. Qualitatively, the results were the same with a larger choice set.

observed nationally in the year 2010[7]. To illustrate, suppose that 5% of the full-size refrigerators available on the US market in 2010 were GE top-freezer refrigerators with a size between 12 cu.ft. and 21 cu.ft., and certified ENERGY STAR. I sample 4 products in my sample (5% X 78 $\approx$ 4%) that fit this description.

In the presence of ENERGY STAR, the provision of energy efficiency is a location decision with a discrete choice component: firms must decide if each product must meet or not the certification requirement. Because of the discrete nature of the decision, point identification of the marginal cost of providing energy efficiency is not possible when all products bunch exclusively at the minimum and ENERGY STAR standards. The first-order conditions with respect to energy efficiency point identify the marginal cost only when some products do not bunch at either of the standards. When such a condition is not met, set identification is however still possible using profit inequalities (Pakes 2010; Pakes, Porter, Ho, and Ishii 2011). My empirical strategy for the estimation of the parameter ϕ then consists of using moment inequalities combined with additional moments provided by a subset of the first order conditions with respect to energy efficiency.

For the moment inequalities estimator, I follow Fox and Bajari (2013); Ellickson, Houghton, and Timmins (2013) and use profit inequalities with the pairwise maximum-score approach proposed by Fox (2007). Put simply, the approach consists of creating small perturbations in the observed strategies of each firm, holding constant the strategies of other firms, and make a pairwise comparison between *observed* and *counterfactual* profits computed at each perturbation. The maximum-score objective function simply rewards the value of ϕ consistent with profit maximization where *observed* profits are greater than *counterfactual* profits.

More formally, define the maximum profits of firm k by π_k^*. The observed product lines and prices are assumed to be the ones maximizing profits, and correspond to the vectors f_k^* and p_k^*. Suppose that firm k changes the energy efficiency level and price of product l and set $f_{kl}^* \rightarrow f_{kl}^{'}$ and $p_{kl}^* \rightarrow p_{kl}^{'}$, but all other products remain the same, including the products offered by competitors. The counterfactual profits for a small change in the value of product l are noted $\pi_k^l \equiv \pi(f_{kl}^{'}, p_{kl}^{'}, f_{-l}^*, p_{-l}^*)$, and $\pi_k^* \geq \pi_k^l$ according to profit maximization.

We do not observe all components of profits, therefore the quantity $\pi_k^* - \pi_k^l$ cannot be computed exactly. In the present application, I do not observe the fixed (sunk) costs of developing each

[7]The year 2010 was chosen because it represents a year where firms seemed to have fully adjusted to the change in certification requirement that occurred in 2008. The choice set observed in 2012 is similar the one observed in 2010. Figure 2(a) thus provides a good representation of the market for this period.

product line, and the cost of certifying a product. Market shares and unit costs, however, are observed (i.e., estimated), which allows me to compute brand manager markups and profits net of fixed and certification costs. I distinguish between the observed and unobserved components of the profit function as follows:

$$\pi_k = r_k(f, p|\phi) - \xi_k J_k - \sum_{j}^{J_k} \zeta_{kj} \mathbf{1}\{f_{kj} \geq f^{ES}\} \tag{8}$$

As in Pakes, Porter, Ho, and Ishii (2011), I distinguish between two types of unobservables. ξ_k represents unobserved fixed costs that firm k faces to develop each product offered. This includes R&D activities, inventory management, and marketing effort. These fixed costs should be economically significant and correlated with firms' characteristics. I then treat ξ_k as an anticipated shock, which plays the role of the structural error term at the source of endogeneity. ζ_{kj} represents the additional fixed cost that firm k incurs to develop a product that meets the certification requirement. I assume that ζ_{kj} is an idiosyncratic and unanticipated cost, which plays the role of measurement error in the estimation. Finally, note that the indicator function identifies the certified products.

The observed component of profits, $r_k(f, p|\phi)$, is the sum of brand manager markups weighted by market shares:

$$r_k(f, p|\phi) = \sum_{j=1}^{J_k} (p_{kj} - c_{kj}(f_{kj}|\phi)) \cdot Q_{kj} \tag{9}$$

For ease of notation, I only express the dependency of r_k on the parameter ϕ. The profits also depend on the constant α_{kl} and the demand parameters, which are both estimated separately, as discussed below.

The objective function of the maximum-score estimator is constructed using the following approach. For the five brands active in the market, I compute the observed component of profits, r_k for all k, using the demand estimates, observed prices, and the cost function evaluated at ϕ. I then perturb the energy efficiency level and price of each product offered, and compute the counterfactual profits at each perturbation. For products that bunch at ENERGY STAR, the perturbation consists of setting the energy efficiency level and price to their optimal level if ENERGY STAR was not in effect. I do this simply by using the first-order conditions of the oligopoly model assuming that there is no certification. For products that do not bunch at ENERGY STAR, the perturbation consists of setting the energy efficiency level equal to the certification requirement. I then find the optimal price associated with this energy efficiency level. Pairwise comparison between optimal and counterfactual profits for a change in the energy efficiency level of product l offered by firm k

then yields:

$$\pi_k^* - \pi_k^l = r_k^*(f^*, p^*|\phi) - r_k^i(f'_{k,i}, p'_{k,i}, f^*_{-i}, p^*_{-i}|\phi) + \zeta_{kj} \tag{10}$$

where the fixed costs of developing product lines cancel out because the number of products offered by each firm is the same at each perturbation. The unobserved certification cost ζ_{kj} remains because for each perturbation a product either gains or loses the certification. I treat ζ_{kj} as an error term with an unknown distribution. I assume that ζ_{kj} are i.i.d. for each firm k and has support equal to the real line. As shown by Manski (1975), those are sufficient conditions for the rank ordering property to hold,[8] which in turn allow me to construct the pairwise maximum-score objective function proposed by Fox (2007). In the present application, an estimate of ϕ is obtained by maximizing:

$$Q(\phi) = \sum_k \sum_l^{J_k} \mathbf{1}[r_k^*(f^*, p^*|\phi) - r_k^l(f'_{kl}, p'_{k,l}, f^*_{-l}, p^*_{-l}|\phi) > 0] \tag{11}$$

where the indicator function takes the value one if the optimal profits are greater that the counterfactual profits. In practice, $Q(\phi)$ takes the forms of a step function, and thus only identifies a range of possible values for ϕ.

Point identification is possible, however, when some products do not exactly meet the minimum and ENERGY STAR standards. For these products, the optimal energy efficiency level is a solution of equation 6, which can be used to form the following moment condition:

(12)

$$M(\phi) = \sum_k \sum_l^{J_k} \mathbf{1}[f_{kl} \neq \underline{\mathrm{f}} \vee f_{ES}] \times \left[Q_{kl}(f^*, p^*) \frac{dc_{kl}(f^*_{kl}|\phi)}{df_{kl}} - \sum_{j=1}^{J_k} (p^*_{kj} - c_{kj}(f^*_{kj}|\phi)) \cdot \frac{\partial Q_{kj}(f^*, p^*)}{\partial f_{kl}} \right] = 0,$$

where the indicator function takes the value one if f_{kl} does not equal the minimum standard ($\underline{\mathrm{f}}$) or the ENERGY STAR standard (f^{ES}).

For the estimation of the constant α_{kl} specific to each product, I rely on the first-order conditions with respect to prices. Because there are $\sum_k J_K$ first-order conditions with respect to prices, and the vector of unit costs, $c(f)$, has $\sum_k J_K$ elements, unit costs are the solution of a just-identified

[8] In this application, the rank property holds if $r_k^*(f^*, p^*|\phi) > r_k^i(f'_{k,i}, p'_{k,i}, f^*_{-i}, p^*_{-i}|\phi)$ implies $F\left(r_k^*(f^*, p^*|\phi)\right) > F\left(r_k^i(f'_{k,i}, p'_{k,i}, f^*_{-i}, p^*_{-i}|\phi)\right)$, where F is the probability that a given level of profits is chosen.

system.[9] For a given value of ϕ and a vector of estimates of unit costs, I can then recover each constant α_{kl} by simply inverting the cost function (Equation 5.2).

To summarize, the cost estimation proceeds as follows:

(1) Guess a value of the parameter ϕ.
(2) Using the first-order conditions with respect to prices, solve a system of $\sum_k J_K$ equations to recover the $\sum_k J_K$ estimates of unit costs ($\hat{c_{kl}}$).
(3) Compute the constants of each cost function using: $\hat{\alpha_{k,l}} = log(\hat{c_{kl}}) - \phi f_{kl}$.
(4) Compute the pairwise maximum-score objective function: $Q(\phi)$.
(5) Compute the moment condition for products do not exactly meet the minimum and ENERGY STAR standards: $M(\phi)$
(6) Return to step 1.

I perform a grid search over the possible values of the parameter ϕ, and select the value that maximizes $Q(\phi)$ and sets $M(\phi)$ the closest to zero, with equal weight to the two objective functions. I do not estimate the standard error for ϕ, but in the simulations I will provide sensitivity tests with respect to this parameter.

5.3. **Demand Estimation**

This section outlines the estimation of a demand model for an energy intensive durable where the different mechanisms by which ENERGY STAR influences purchasing decisions are explicitly modeled. The model has enough structure to simulate demand with and without ENERGY STAR, and a rich set of counterfactual policy scenarios.

The purchase decision is modeled as a two-step process where consumers first update their beliefs about energy costs by collecting and processing different pieces of information, and then make a purchase decision. In this framework, consumers are heterogeneous in the costs of collecting and processing energy information, which leads to heterogeneity in the way consumers value energy efficiency. The existence of these costs explains why some consumers either dismiss the energy efficiency attribute or rely on ENERGY STAR, although accurate information about energy costs is readily available. When the costs of collecting and processing energy information are high, a

[9]In matrix notation, the first-order equations with respect to prices are: $D(f,p)+D_p(f,p)\times[p-c(f)] = 0$, where D is a vector of demand for a given firm, and D_p is the Jacobian matrix with respect to prices. When D, D_p and p are known, the vector of unit cost, $c(f)$, can be obtained simply by matrix inversion.

large fraction of consumers dismiss energy efficiency, and firms respond by under-providing energy efficiency. The market for energy efficiency thus fails. Additionally, if energy prices do not reflect the social costs, there are rationales for alternative policy instruments, such as ENERGY STAR, that induce consumers to adopt more energy efficient technologies.

The decision to collect and process energy information is treated as a latent decision unobserved by the econometrician. The choice model takes the following general form:

$$Q_{irt}(j) = \sum_{e=\{U,ES,F\}} H_{irt}(e) P^{e}_{irt}(j) \tag{13}$$

where e represents the level of knowledge about energy costs that each consumer acquires. Consumers fall into three mutually exclusive categories. They can be uniformed ($e = U$). In such case, they will not know the energy cost of each product and the meaning of the ENERGY STAR certification. They can be knowledgeable about ENERGY STAR ($e = ES$), but not about the exact energy cost of each product. Finally, they can be fully informed ($e = F$) and know the energy cost of each product in their choice set. $H_{irt}(e)$ is the probability that consumer i, living in region r at time t, acquires knowledge e, and $P^{e}_{irt}(j)$ is the choice probability conditional of the level of knowledge. $Q_{irt}(j)$ is the choice probability for product j in region r and time t, for consumer i.

The alternative-specific utilities that enter the conditional choice probabilities $P^{e}_{irt}(j)$ are:

$$\begin{aligned}
&\text{e=F:} \quad U^{F}_{ijrt} = -\eta P_{jrt} + \psi R_{rt} X D_{jt} + \tau^{F} D_{jt} - \theta C_{jr} + \delta_j + \epsilon^{F}_{ijrt} \\
&\text{e=ES:} \quad U^{ES}_{ijrt} = -\eta P_{jrt} + \psi R_{rt} X D_{jt} + \tau^{ES} D_{jt} - \theta ESAVINGS_r X D_{jt} + \delta_j + \epsilon^{ES}_{ijrt} \\
&\text{e=U:} \quad U^{U}_{ijrt} = -\eta P_{jrt} + \gamma_j + \epsilon^{U}_{ijrt},
\end{aligned}$$

where δ_j is the quality of the product, P_{jrt} is the price, D_{jt} takes the value one if product j is certified ENERGY STAR at time t and zero otherwise, R_{rt} is the rebate amount offered for ENERGY STAR products, and ϵ_{ijrt} is an idiosyncratic taste parameter. Assuming that the idiosyncratic taste parameters ϵ are extreme value distributed, the probabilities P^{e}_{irt} take the form of a multinomial logit.

In this framework, there are three mechanisms that lead to the adoption of ENERGY STAR products. First, there are the expected energy savings, i.e., the fact that ENERGY STAR products have lower energy costs on average. When $e = F$, consumers can perfectly forecast the energy operating costs of each product. The variable C_{jr} is the product of the annual electricity consumption of refrigerator j and the average electricity prices in region r. Consumers then know the exact difference in electricity costs between each certified and non-certified model. When $e = ES$, the term $ESAVINGS_r$ is the difference between the average energy operating costs of ENERGY STAR and non-ENERGY STAR refrigerators, in region r. For these consumers, the certification serves as a heuristic; instead of computing the exact difference in energy costs, they rely on a proxy that reflects the average savings. For both $e = F$ and $e = ES$, the parameter θ captures the sensitivity to energy operating costs, and thus determines how the monetary value of the energy savings influences choices.

The second mechanism is the effect of the label itself, which is captured by the parameters τ^F and τ^{ES}. The label effect rationalizes a number of behavioral effects, which cannot be identified separately in the data. If consumers value ENERGY STAR products beyond their lower energy operating costs, this will simply be captured by these parameters. The label effect captures the branding strategy of the certification and plays a crucial role in determining firms' strategies.

The third mechanism is the effect of rebates for ENERGY STAR products. This is captured by the parameter ψ.

In Houde (2012), I develop a fully structural approach to model the latent probabilities $Q_{irt}(e)$. For the present application, I use a simpler version of the model where $Q_{irt}(e)$ is a multinomial logit. The choice model given by Equation 5.3 then becomes a special case of a mixed logit model with three discrete latent types. The latent probabilities are specified as follows:

$$Q_{irt}(e) = \frac{e^{V_{irt}(e)}}{\sum_k e^{V_{irt}(k)}} \tag{14}$$

with

$$\begin{aligned} V_{irt}(e=F) &= -K^F - \beta^F X_i + \gamma_1^F MeanElec_{rt} + \gamma_2^F VarElec_{rt} + \gamma_3^F NbModels_{rt} \\ V_{irt}(e=ES) &= -K^{ES} - \beta^{ES} X_i + \gamma_1^{ES} MeanES_{rt} + \gamma_2^{ES} VarES_{rt} + \gamma_3^{ES} NbModels_{rt} \\ V_{irt}(e=U) &= 0 \end{aligned} \tag{15}$$

where K^e is a constant, and X_i is a vector of consumer demographics. The other variables aim to capture factors that could influence consumers' decision to collect energy information, and are specific to the choice set faced by each consumer. $MeanElec_{rt}$ and $VarElec_{rt}$ are the mean and variance in electricity costs for all products offered in region r at time t. $MeanES_{rt}$ and $VarES_{rt}$ are the mean and variance of the proportion of ENERGY STAR models offered. Finally, $NbModels_{rt}$ is the number of models in the choice set in a given region. Intuitively, the latent probabilities are akin of a selection of model that determines why different consumers *self-select* to attend particular pieces of information.

Estimation. The estimation is performed by forming the individual choice probabilities for each consumer, and estimating the model via maximum likelihood. I allow heterogeneity with respect to income by estimating the model separately for three different income groups. Three large sub-samples of transactions was randomly drawn from the universe of transactions made by households that belong to a particular income group. I distinguish between households with income of less than ≥$50,000, households with income between $50,000 and $100,000, and households with income of more than $100,000. Given the large number of transactions, the lost of efficiency from sub-sampling is small.

The estimation is performed with a two-step maximum likelihood procedure to ease computed due to the large number of fixed effects. In the first step, product fixed effects are recovered by estimating a simple conditional logit, with no unobserved heterogeneity, for each income group. The alternative-specific utility is given by:

$$U^F_{ijrt} = -\eta P_{jrt} + \psi R_{rt} X D_{jt} + \tau D_{jt} - \theta C_{jr} + \delta_j + \epsilon_{ijrt} \tag{16}$$

The second step estimates the mixed logit model, but uses the product fixed effects from the conditional logit as data. The standard errors of the behavioral parameters obtained in the second step are corrected using the Murphy and Topel (1985)'s approach.

The choice model does not contain an outside option. The purchase decision being modeled is conditional on the decisions to replace a refrigerator and go shopping at a particular store. Therefore, the price coefficient corresponds to a short-run elasticity.

Identification. The following sources of variation identify the various behavioral parameters. The sample contains large and frequent variations in prices. Promotions for each refrigerator model offered last on average a week (Table 3), and are usually determined at the national level. I exploit the temporal variation in prices to identify consumers' sensitivity to the retail price of a particular model. From the transaction level data, I construct weekly and store-specific price time series for each product, and use the average tax rate observed in each store and trimester to compute prices gross of sales tax.

Following the revision of the ENERGY STAR standard for refrigerators in April 2008, a large number of refrigerator models lost their ENERGY STAR certification (Table 3). Using data that cover a time period before and after the revision in the standard, it is possible to observe the same refrigerator model being sold at the same store, with and without the ENERGY STAR label. This variation in labeling can then be used to identify how consumers are influenced by the ENERGY STAR label.

To control for the effects of product entry and exit at the time of decertification, I construct an unbalanced panel for each refrigerator model that is store and month specific. More precisely, if at least one refrigerator model has been sold during a particular month at a given store, I assume that all consumers shopping at this store during this month could purchase this model.

I observe the same refrigerator models being sold at stores located in different electric utility territories. This allows me to control for product fixed effects and to use cross-sectional variation in average electricity prices and rebates across regions to identify the sensitivity to electricity prices and rebates. Average electricity prices are state specific, and rebates are county-specific.

The product fixed effects capture the effect of all attributes that do not vary over time and regions, and remove part of the endogeneity in prices. In Houde (2012), I show that the model is robust to different specifications. Using average electricity prices at the county level reduces the impact of electricity costs, but adding brand-week fixed effects and additional control for time-varying unobservables has little impact. Finally, using instruments for prices changes the coefficient on prices slightly, but the impact is not economically significant.

6. Results

6.1. Cost Estimation

Performing a grid search over the possible values of the parameter ϕ, I found that $\phi = 451$ yields the largest value for the maximum-score estimator, while bringing the moment condition $M(\phi)$ the closest to zero. At this value of ϕ, a 1% increase in energy efficiency for a refrigerator model consuming 550 kWh/year, increases the unit cost by 0.82%. Is this a reasonable value? I next present an alternative estimator that relies on minimal structural assumptions, and does not require information about demand, and obtain an estimate of similar magnitude.

Alternative Estimator: Marginal Cost of Providing Energy Efficiency. In the refrigerator market, manufacturers commonly offer product lines that consist of a group of three to ten refrigerator models with similar overall design, such as the size and style (top freezer, side-by-side, bottom-freezer), but that differ with respect to less important attributes, such as the ice-maker option, the finish option (stainless or not), and the energy efficiency levels. In my sample, I observe 78 product lines offered between 2007 and 2011 with very similar refrigerator models that have different energy efficiency levels, but otherwise similar attributes. With these product lines, I am able to match 155 refrigerator models with at the least another model that has the same size, style, brand, door material (stainless or not), ice-maker option, defrost technology, and entered the market the same year (Table 4). Matched refrigerators differ only in color and energy efficiency levels; all other *observed* attributes are identical.

For all matched refrigerator models (N=155), I simply exploit variation in energy efficiency within product line, and estimate the marginal cost of providing energy efficiency by regressing the log of the wholesale price on a product line fixed effect, dummies for color, and a proxy for energy efficiency:

$$ln(price_{j,r}) = \alpha + \gamma_{j,j'} + \sum_{k}^{K} \gamma^k C_j^k + \phi Efficiency_j + \epsilon_{j,r}, \tag{17}$$

where $\gamma_{j,j'}$ is a product line fixed effect that is common to the matched refrigerator models j and j', and C_j^k are dummy variables that are equal to one if refrigerator j is of a given color. For the proxy for energy efficiency, I use the same functional form than for the structural estimator, where energy efficiency is defined as the inverse of the annual electricity consumption. The estimate of the parameter ϕ is 362, which corresponds to a cost elasticity of 0.66% (Table 4).

6.2. **Demand Estimation**

Table 5 presents the estimates of the demand for all three income groups. Focusing on the price coefficients, we observe an inverse correlation between consumers' sensitivity to prices and income levels, i.e., the marginal utility of income decreases with income. Meanwhile, lower-income consumers are also less sensitive to electricity costs. To interpret the magnitude of the estimate of the sensitivity to electricity costs, we need to compare η and θ. Instead of simply reporting the ratio, I make additional assumptions and compute the discount rate implied by these parameters. I first assume that consumers form time-unvarying expectations about annual electricity costs. Moreover, I assume that consumers do not account for the effect of depreciation, and compute the lifetime electricity costs ($LC_{r,j}$) by summing and discounting the expected annual electricity costs ($C_{r,j}$) over the lifetime of the durable:

$$LC_{r,j} = \sum_{t=1}^{L} \rho^t C_{r,j} = \frac{1-\rho^L}{1-\rho} C_{r,j}, \tag{18}$$

where L is the lifetime of the durable, $\rho = 1/(1+r)$ is the discount factor, and r is the (implied) discount rate.

Consistent with the fact that $|\eta|$ corresponds to the marginal utility of income, the coefficient for the sensitivity to annual energy costs in the demand model (θ) is a reduced form parameter that corresponds to:

$$\theta = \eta \frac{1-\rho^L}{1-\rho} \tag{19}$$

Assuming a refrigerator lifetime of 18 years, the implied discount rate is 4.6% for households with an income larger than \$100K, 10.9% for households with income between \$50K and \$100K, and 11.6% for households with income of less than \$50K. These discount rates rationalize the purchase decision of the share of perfectly informed consumers, but do not represent aggregate demand. The behavioral estimates of the simple conditional logit yield implied discount rates of 19.9%, 37.9% and 161.5% for the high, medium, and low income groups, respectively. These rates are high, which suggests that consumers, on average, undervalue energy operating costs. The estimates from the mixed logit model makes it clear that this undervaluation is due to unobserved heterogeneity in information acquisition costs, which explains the existence of a consumer type that dismisses the energy efficiency attribute altogether.

Looking at the latent probabilities, households in the lowest income group have a high probability of being uninformed ($e = U$), while households in the highest income groups are the most likely to be perfectly informed about energy costs ($e = F$). Medium and high income households have a high probability to rely on ENERGY STAR, but for low income households this probability is close to zero. ENERGY STAR products are thus being purchased by the most affluent consumers, and energy efficiency tends to be dismissed altogether by households with the lowest income. For consumers that rely on the certification ($e = ES$), the effect of the ENERGY STAR label is positive, relatively large, and varies across income levels. The estimate of the label effect τ^{ES} translates into a willingness to pay (τ^{ES}/η) for the certification itself that ranges from \$47 to \$154. For the perfectly informed consumers, the label effect (τ^F) is small and even negative. This suggests that for consumers that rely on an accurate measure of energy costs, the ENERGY STAR products are not valued beyond the monetary value of the energy savings.

7. **Policy Analysis**

The main analysis consists in simulating the US refrigerator market with and without the ENERGY STAR certification, and comparing welfare and other metrics. For all scenarios, the demand is simulated with a random sample of 500 households taken from the whole sample of transactions. Therefore, households differ with respect to demographic information and the region where they live. The price of electricity faced by each household is the average electricity price at the state level for the year 2010. All households have access to a \$50 rebate for ENERGY STAR products. Unless otherwise indicated, the ENERGY STAR requirement is set to the level in effect in 2010 (20% relative to the minimum standard).

The policy analysis is performed by bootstrapping the model 100 times. For each bootstrap iteration, the demand parameters are sampled from their estimated distribution, and the model solved for the Nash equilibrium using the Gauss-Siedel algorithm. The results reported are the mean and standard deviation of the difference in metrics between policy scenarios.[10] The metrics considered to measure welfare are the consumer surplus, producer surplus, externality costs, and change in government revenue.

Consumer Surplus. In the demand model, there is a discrepancy between the notions of decision and experience utility, because consumers that rely on the ENERGY STAR certification ($e = ES$) or remain uninformed ($e = U$) have imperfect knowledge about electricity costs. Therefore, the utility experienced after the purchase decision may not be the same as the one anticipated at the time of purchase.[11] To measure the change in consumer surplus, I simply assume that the expected utility faced by the fully informed consumer type ($e = F$) coincides with the *experienced* utility that each consumer will receive over the lifetime of a refrigerator. Put another way, fully informed consumers have rational and unbiased expectations. Under this assumption, the expected consumer surplus (ESC_{irt}), for consumer i that lives in region r and makes a purchase at time t, is then given by:

$$ECS_{irt} = \frac{1}{\eta_i} \sum_{j}^{J} \sum_{e} \hat{H}_{irt}(e) \cdot \hat{P^e}_{irt}(j) \cdot \Big(\hat{\gamma}_j + \hat{\tau_i}^F D_{jt} - \hat{\eta}_i P_{jrt} + \hat{\psi}_i R_{rt} X D_{jt} - \hat{\theta}_i C_{jr} \Big) , \tag{20}$$

[10]That is, I report the mean of the differences, and not the difference of the means.

[11]Allcott, Mullainathan, and Taubinsky (2012) refer to such discrepancy as an internality. In the present model, the costs of acquiring and collecting energy information and, possibly, the ENERGY STAR label are at the source of the internality.

The term $\frac{1}{\eta_i}$ is the inverse of the marginal utility of income of household i, and is used to convert utils into dollars. All estimated paramaters vary across income groups. The above measure corresponds to the consumer surplus obtained over the entire lifetime of a refrigerator. To obtain an annual measure, I assume that consumers will own (and believe they will own) their refrigerators for 18 years, and compute the corresponding annuity using the implied discount rate specific to each income group. Whether the label effect should be part of the consumer surplus is open to discussions. I will report the results without the label effect (parameters τ^{ES} and τ^{F}) assuming that the label affects decisions, but not how a consumer experiences the various services provided by a refrigerator.

Producer Surplus. The producer surplus is the sum of the profits made by each brand manager. Profits are computed by multiplying markups with the simulated market shares, where the markups are the difference between prices and unit costs. The change in manufacturers' profits are not accounted for in the producer surplus. I conjecture that under most circumstances, the sign of the change in profits, in a given scenario, would be the same for brand managers and manufacturers. When this hold, the magnitude of the change in profits reported can be considered a lower bound.

Externality Costs. The externality costs associated with electricity generation account for the emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrous oxide (NO_x). The dollar damages of the externality costs under each scenario are computed by taking the product of the average electricity consumption purchased, the emission factors, and the damage costs per unit of emissions. The average electricity consumption purchased is the average of the electricity consumption of the refrigerators sold, weighted by market shares. Table 6 presents the emission factors and the damage costs. For the analysis, the high estimates of the externality costs are used, which translates to a cost of $0.079/kWh.

Government Revenues. The change in government revenues includes only the revenues from the Pigouvian tax. The administrative costs to operate the ENERGY STAR program are not considered. According to the US Government Accountability Office (GAO), the EPA and the DOE have spent $57.4 M/year, on average, during the period 2008-2011 to run the ENERGY STAR program. If we assume that more than 60 product categories are covered by the ENERGY STAR program, a naive estimate of the administrative costs of the program for the refrigerator market alone can be obtained by assuming that the overall costs are distributed proportionally across all product categories. Under this assumption, the administrative costs would be $0.96 M/year.

To obtain an estimate for the whole US refrigerator market, I scale all of the above measures by the market size. I use the annual shipments of refrigerators in the US for the year 2010, which is 9.01 million units (DOE 2011).

7.1. **Results**

Validity of the Model. Before presenting the welfare analysis, I first demonstrate that the model has good internal validity. Figure 6(a) shows the distribution in energy efficiency predicted by the model under ENERGY STAR. Compared to the distribution observed in 2012 for the whole US market (Figure 2(a)), the model replicates well the bunching at the minimum and ENERGY STAR standards, with a higher share of models that just meet the certification requirement. The model over-predicts the number of products that exceed the ENERGY STAR requirement, but under-predicts the number of products located between the minimum and ENERGY STAR standards.

These discrepancies can be explained, in part, by the fact that the model is static, while in practice product line decisions and the certification requirement are determined dynamically. Clearly, products located between the minimum and ENERGY STAR standards correspond to models that met the previous certification requirements, but did not exit the market. These previous requirements are not captured by the model. In a dynamic framework, firms may also find it optimal to under-provide energy efficiency if the certification requirement is revised based on the models offered on the market. The intuition is that offering highly efficient models may act as a signal to the regulator. Firms might then strategically retain innovation in energy efficiency to keep the certification requirement not too stringent. These incentives are not captured, which could explain that the model predicts that a small number of highly energy efficient models should be offered. The extension to a fully dynamic framework is left for future research.

By strategically determining energy efficiency levels, firms differentiate their products and can charge prices above marginal costs. The ability of the model to replicate pricing strategies is crucial for the welfare analysis. Figure 5(a) compares the markups predicted by the model and the observed markups.[12] For proprietary reasons, the markups are normalized. Each normalized markup corresponds to the ratio of the percentage markup of a product and the lowest percentage markup observed in the retailer data. Qualitatively, the patterns are similar. Predicted markups are, however, higher on average, which suggests that the model tends to overestimate the degree of market power. Nonetheless, the model does well in predicting which refrigerators should have the

[12] The observed markups are the retailer prices minus wholesale prices divided by the retailer prices.

highest markups. The model thus provides a good approximation of how firms price discriminate in this market.

The Overall Welfare Effects of ENERGY STAR. The main estimates of the overall effects of ENERGY STAR are presented in Column I of Table 7. Each metric represents the average difference in equilibrium outcomes between the scenario without certification and the scenario with certification.

Focusing on energy savings, the model predicts that by removing ENERGY STAR, the average electricity consumption of a refrigerator purchased[13] would increase by 43 kWh/year, or about 8%. Without certification, firms offer products that mostly bunch at the minimum standard, with a few products that exceed the minimum (Figure 6(b)). The most energy efficient products are, however, amongst the most popular, and attract significant market shares ($\sim$35%). A first important conclusion is that in a market not subject to certification, energy efficiency is still provided and sought by the fraction of consumers that value this attribute.

If we assume that without certification all refrigerators offered would just meet the minimum standard (Column III), the electricity consumption of a refrigerator purchased increases by 104 kWh/year, on average, relative to a market with ENERGY STAR. Ignoring firms' incentive to provide energy efficiency to some consumers in the absence of certification thus leads to grossly overestimate energy savings.

Removing the certification leads to a large loss in profits; about $886 million per year, or $97 per refrigerator sold. A reduction of $97 in retail price is economically significant, but appears to be reasonable in this market. Considering that the average price paid for a full-size refrigerator was $1,114 in 2008 (Table 3), $97 corresponds to an average reduction in retail price of 8.7%. To further put this number in perspective, the 2010 DOE's national impact analysis[14] of minimum standards for refrigerators assumes that the retailer markup was 37% of the final price. This percentage markup translates into a markup of $242 for top-freezer, $375 for bottom-freezer, and $462 for side-by-side. An average reduction of $97 in markup thus appears plausible in this market.

Figure 5(b) compares the estimated markups for each product in a market with and without certification. Markups decrease sharply for most products. An important conclusion is that the certification affects all prices in equilibrium, even products that were not certified in the first place.

[13]The average electricity consumption of a refrigerator purchased is the sales-weighted average of the annual electricity consumption of all refrigerator models offered.

[14]The models used by the DOE for the national impact analysis can be requested to the author.

Without ENERGY STAR, products are less differentiated in the energy efficiency dimension, which increases competition, and leads to lower markups. The fact that some consumers value highly the ENERGY STAR label thus allows firms to screen consumers in the energy efficiency dimension and extract consumer surplus from all consumers, even the ones that do not value the certification.

Interestingly, when ENERGY STAR is not in effect, the products with the highest markups are the ones with the highest energy efficiency levels (Figure 5(c)). Without certification, firms thus still distort energy efficiency levels to extract rents from consumers. Note also that the products with the highest markups are also amongst the cheapest (Figure 5(d)). On one hand, this implies that when ENERGY STAR is not in effect, energy efficiency can be accessible to all income groups. On the other hand, the fact that these products have the largest markups also suggests that the exercise of market power falls disproportionately on lower income households.

Consumers are slightly better off without ENERGY STAR. Refrigerators are cheaper, on average, although less energy efficient. Therefore, the reduction in prices is large enough to compensate for the increase in lifetime electricity costs. Note that the change in consumer surplus reported in Table 7 excludes the effect of the ENERGY STAR label. That is, the welfare measure takes the stand that the label does not affect utility, although it impacts decisions. Adding a modest label effect to the consumer surplus of the order of \$3.5/consumer would be enough to change the sign of the consumer surplus. Whether or not consumers are better off under ENERGY STAR is then unclear.

Accounting for the changes in externality costs, consumer surplus, and profits, welfare decreases when ENERGY STAR is not in effect. The bulk of the welfare loss comes from the loss in profits. This suggests that if the ENERGY STAR program were to be removed, firms might respond by developing their own certification. A world without ENERGY STAR might, therefore, not be a world without certification.

Sensitivity Analysis. Columns III to VII of Table 7 present various sensitivity tests. For a larger marginal cost of providing energy efficiency, where $\phi = 650$, the model predicts, as expected, more bunching at the minimum standard when ENERGY STAR is in effect (Figure 6(c)). Removing the certification leads to slightly larger energy savings, but the results are qualitatively similar to the main scenario.

For a low marginal cost, where $\phi = 150$, removing the certification leads to a decrease in electricity consumption. Put another way, ENERGY STAR leads to an increase in electricity consumption. This result is explained by the fact that with a lower cost of providing energy efficiency, firms offer more models that exceed the minimum standard (Figure 6(f)), and they can do so at a lower cost. Without certification, the market shares of the most energy efficient products increase enough to dominate. This result highlights an important unintended consequence of ENERGY STAR. By inducing bunching at the certification requirement, ENERGY STAR can crowd out energy savings.

The third sensitivity test investigates the effect of the label effect. For this simulation, the label effect was reduced by half for all income groups (and consumer types: τ^F and τ^{ES}). As a result, firms offer less products that bunch at ENERGY STAR (Figure 6(h)). Nonetheless, bunching still crowds-out energy savings; removing ENERGY STAR leads to a reduction of 15 kWh/year in electricity consumption purchased (Table 7). This suggests the following trade-off in implementing the ENERGY STAR program. In markets where ENERGY STAR may not be valued highly or recognized by only a small fraction of consumers, it may be better to not rely on a coarse certification. Another important point to note is that firms profit much less from ENERGY STAR in this scenario. Reducing the willingness to pay for the label by half, reduces profits by about eightfold. Firms ability to extract rents from consumers thus rises quickly as the label becomes more valued.

Optimal Certification Requirement. The EPA determines the ENERGY STAR certification requirements based on a number of criteria, such as the number of certified models in the marketplace, market shares, and the best available technology. The requirements adopted are often the outcome of a negotiation between manufacturers, environmental and consumer advocacy groups, and governmental agencies. A natural question to ask is what would be the optimal requirement from the point of view of the different stakeholders?

To answer this question, I simulate the model for different increments of the certification requirement. I restrict the analysis to a binary certification where the requirement is set relative to the minimum energy efficiency standard.[15] A certification requirement of 5% means that a product can be certified ENERGY STAR if it consumes at least 95% less electricity than the minimum standard. Table 9 presents the results. Each estimate corresponds to the difference in a market with and without certification. A positive sign means that adding the certification leads to an increase relative to a market without certification. For instance, if the requirement is set at 5%, the externality costs increase by \$2M/year relative to a market without certification. The externality

[15]This is the approach currently being implemented by the EPA. I consider 5% increments because this is the size of the increment that ENERGY STAR has historically considered.

costs are then minimized if the requirement is set at 25%, which corresponds to a requirement slightly more stringent than the one in effect in 2010. Profits are maximized when the requirement is 5%, i.e., firms prefer a market with certification, but with the least stringent requirement. Consumers are better off with no certification, although for very stringent requirements the change in consumer surplus is close to zero. If we subtract the externality cost from the consumer surplus, the optimal requirement would be 25%. Because the change in profits dominates all other metrics, the requirement that maximizes total welfare is the one that maximizes profits.

These results suggest that if the ENERGY STAR program were to be solely managed by manufacturers, they would use the certification merely as a branding strategy, and the program would not contribute to reduce energy demand. In the long term, the value of the brand would, however, deteriorate as consumers come to realize that certified products are only sightly more energy efficient than non-certified products. Of course, firms might anticipate this decline, and long-term concerns for the reputation of the certification might induce firms to adopt more stringent requirements in the short run.

Interactions with Market Failures. When the ENERGY STAR certification program was established in 1992, the program was motivated by the existence of two potential market failures: the negative externalities associated with electricity generation, and the fact that information about the costs of operating energy-intensive durables was either incomplete or costly to acquire.[16] I now investigate how the ENERGY STAR certification interacts with these two market failures.

In the first scenario, the negative environmental externalities associated with electricity generation are internalized with a Pigouvian tax. The price of electricity is increased by $0.079/kWh for all consumers, and the revenues of the tax are redistributed via a lump-sum payment.

With higher electricity prices, demand for energy efficient products increases. This, in turn, induces firms to offer more energy efficient models. In a market without ENERGY STAR, but higher electricity prices, firms differentiate their products more; a small number of highly energy efficient products are offered, but most products just meet the minimum (Figure 7(b)). When ENERGY STAR is in effect, there is still strong bunching at the certification requirement (Figure 7(a)). As electricity prices further increase, firms' incentive to bunch at ENERGY STAR, however, decreases. Figure 8 illustrates this and shows how electricity prices impact product differentiation. Each panel plots the predicted distribution of energy efficiency for different electricity prices in a

[16]The first products covered by the ENERGY STAR program were computers and monitors for which there were no readily accessible information about energy usage.

market subject to ENERGY STAR. For low electricity prices, products bunch at ENERGY STAR; firms then use the certification to differentiate. As electricity prices increase, some models exceed the requirement, and we observe less bunching. For high electricity prices, ENERGY STAR has virtually no impact, and firms maintain a maximum amount of differentiation. That is, firms need to differentiate their products more to screen consumers with high and low valuation of energy efficiency. Highly energy efficiency models are offered to capture consumers that value them the most, but energy efficiency is under-provided to other consumers to ensure that high valuation consumers prefer purchasing the most energy efficient models. Offering products that bunch at the ENERGY STAR requirement then becomes sup-optimal, as these products are too energy efficient for some consumers, but not enough for others.

In sum, if externality costs were to be internalized and reflected in electricity prices, a certification would become less relevant (Table 8). Due to the existence of imperfect competition, energy efficiency would, however, still be under-provided, but neither a certification nor a Pigouvian instrument would adequately address this market failure.

In the second scenario, the share of uninformed consumers is reduced for all income groups. Specifically, I fix the proportion of uninformed consumers to 4%, and assume that consumers are either perfectly informed or rely on ENERGY STAR with equal chances. This scenario aims to represent a nudge policy that decreases the costs of collecting and processing energy information. As expected, this induces firms to provide more energy efficient products (Figure 7(d)). In this scenario, ENERGY STAR crowds out energy savings. Without certification, the market shares for the most energy efficient products are high enough to reduce the average electricity consumption purchased relative to a market with ENERGY STAR. Firms still benefit under this scenario (Table 8), but less than under the basecase scenario. The presence of a share of uninformed consumers thus helps firms to screen consumers, and extract rents. This result relates to the findings of Gabaix and Laibson (2006) who show that firms might price discriminate between sophisticated and unsophisticated consumers by shrouding some attributes. In the present context, if we were to fully endogenize how firms dissipate product information, firms would have an incentive to strategically manipulate information to leave some consumers uninformed with respect to energy costs.

8. Conclusion

This paper develops an economic framework to perform a welfare analysis of the ENERGY STAR certification program accounting for firms' strategic response. The various mechanisms by which the certification can influence consumers are also explicitly modeled. The welfare analysis offers a cautionary tale on how certification, and more generally, nudges and information-based policies should be used, especially when it comes to address environmental externalities. Historically, ENERGY STAR has been managed like a marketing program where a strong branding effect has been sought, and deemed a successful metric. I show that consumers' high willingness to pay for the ENERGY STAR label favors the adoption of more energy efficient products, and induces firms to offer more of these products. The certification thus contributes to reducing environmental externalities. However, the fact that consumers value the ENERGY STAR certification highly allows firms to charge higher prices, and consumers pay too much for energy efficiency. I also find that the certification may have the unintended consequence of increasing electricity consumption by crowding out demand for highly energy efficient products.

Firms' ability to strategically adjust energy efficiency levels is crucial to the analysis. The existence of imperfect competition in the market for energy intensive durables implies that the provision of energy efficiency is sub-optimal, and neither a certification nor a Pigouvian instrument adequately addresses this market failure. The analysis also highlights that the presence of information acquisition costs may facilitate the exercise of market power. Altogether, this paper shows that accounting for firm behavior is crucial for the design and evaluation of policies used to manage energy demand.

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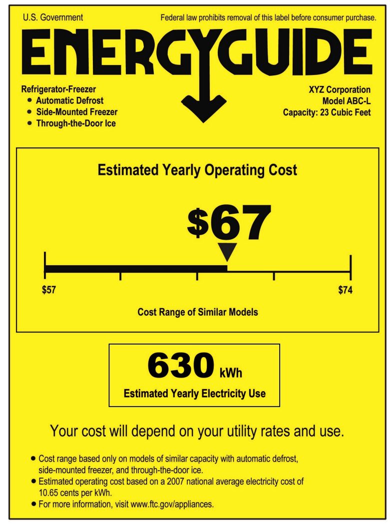
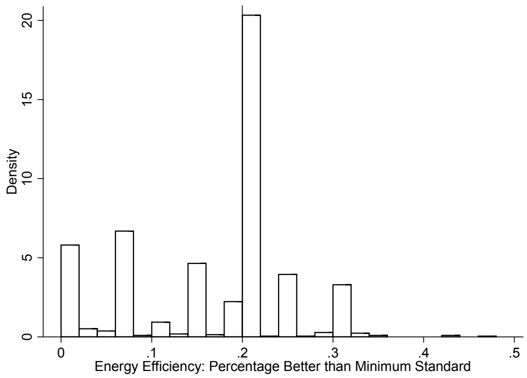
9. **Figures and Tables**

(a) ENERGY STAR Label

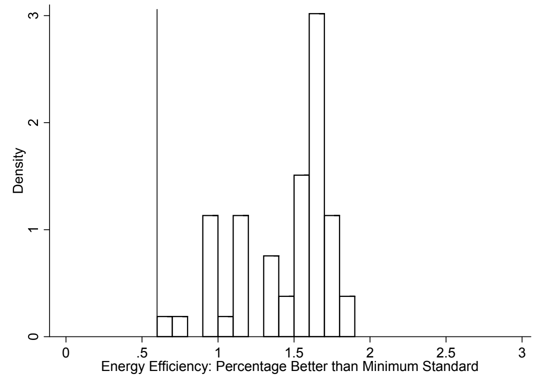


(b) EnergyGuide Label

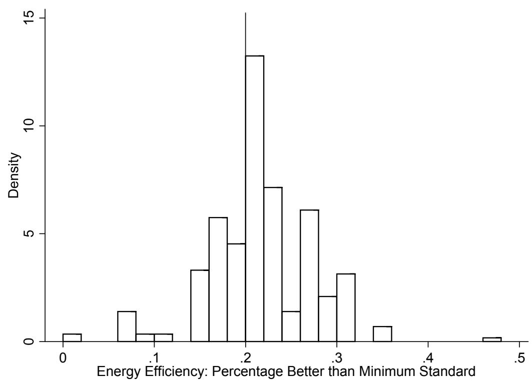
Figure 1. ENERGY STAR and EnergyGuide Labels



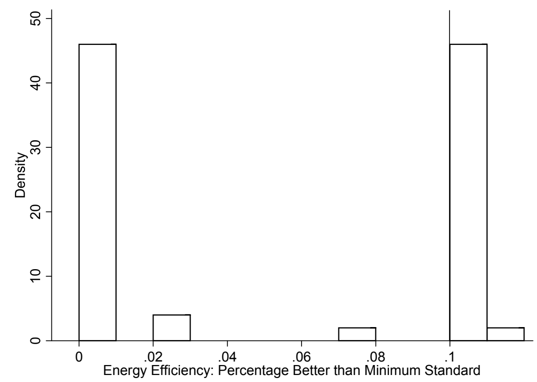
(a) Refrigerators



(b) Clothes Washers



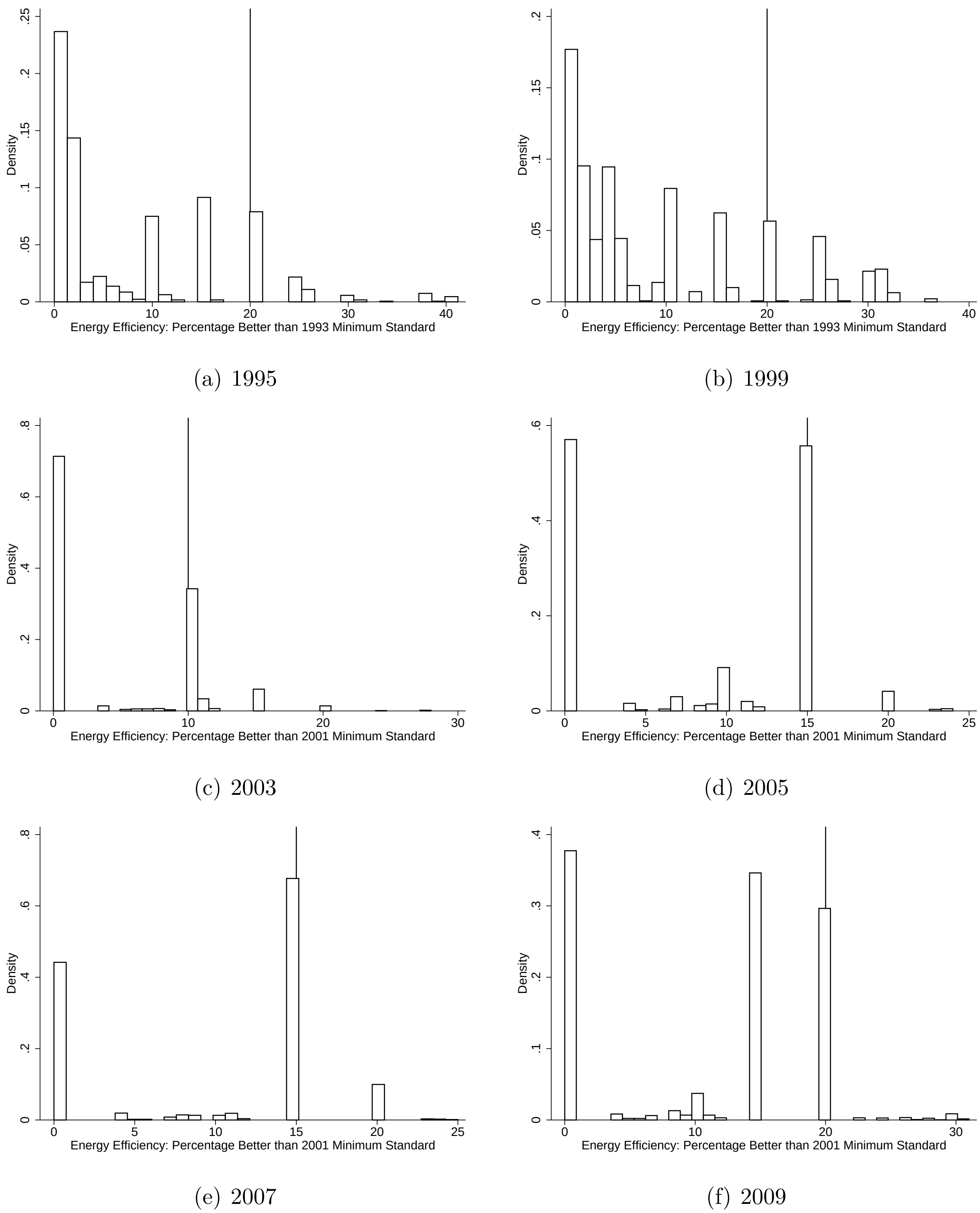
(c) Dishwashers



(d) AC

Figure 2. Energy Efficiency Offered, Year 2012

Notes: Each panel plots the empirical density of the energy efficiency levels offered for different appliances. The x-axis is the percentage difference in energy efficiency relative to the federal minimum energy efficiency standards. The ENERGY STAR certification requirement is identified by the vertical line. Source: websites of major online retailers: Lowes, Best Buy, and Sears.



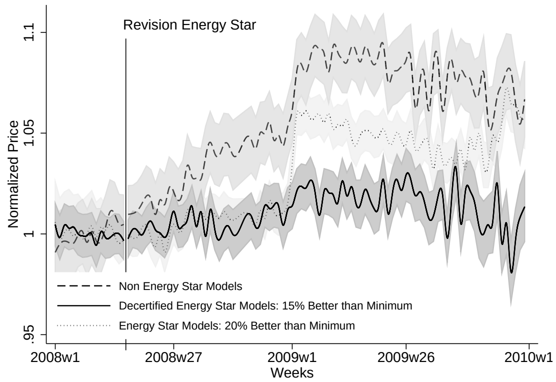
(a) 1995 (b) 1999

(c) 2003 (d) 2005

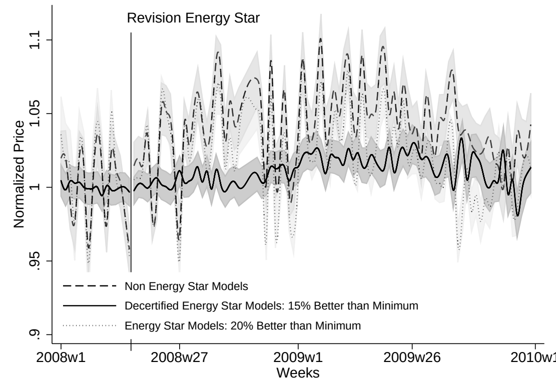
(e) 2007 (f) 2009

FIGURE 3. Energy Efficiency Offered, Full-Size Refrigerators: 1995-2009

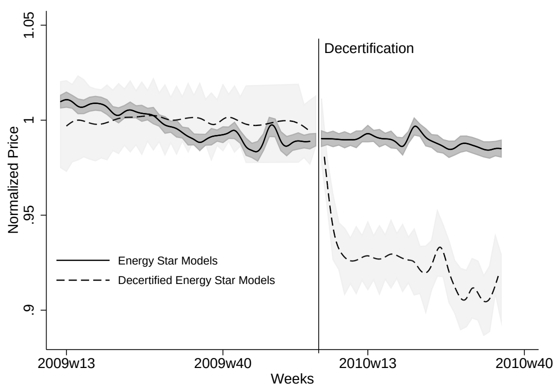
Notes: Each panel plots the empirical density of the energy efficiency levels for full-size refrigerators offered in a given year. The x-axis is the percentage difference in energy efficiency relative to the federal minimum energy efficiency standards. Source: California Energy Commission appliance database and Federal Trade Commission.



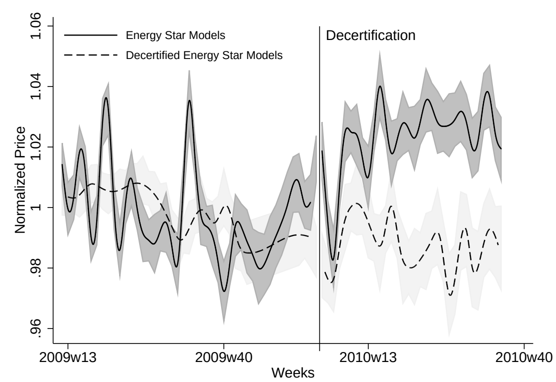
(a) MSRP: 2008 Revision



(b) Promo. Prices: 2008 Revision



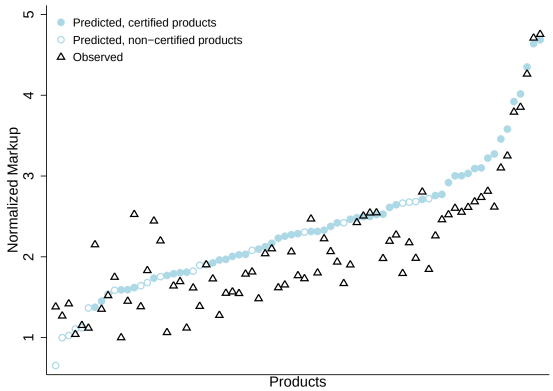
(c) MSRP: 2010 Decertification



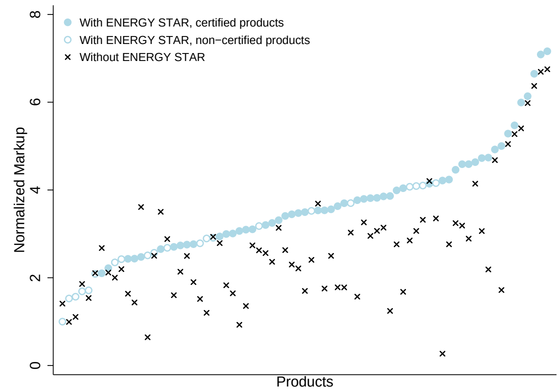
(d) Promo. Prices: 2010 Decertification

Figure 4. Prices Before and After Decertification

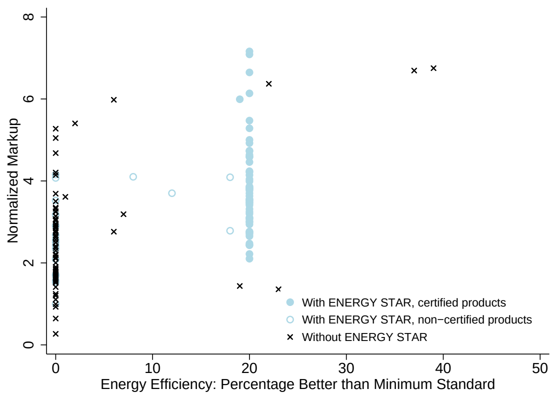
Notes: Each panel displays average normalized weekly prices, with 5% confidence intervals, of refrigerators that belong to different efficiency classes. The normalized price for each model is the weekly price (MSRP or promotional) divided by its average weekly price. The average normalized price and standard errors in each efficiency class are computed by fitting a cubic spline on normalized prices. In panels a) and b), three efficiency classes are considered: models that were not certified Energy Star before and after the revision (less than 15% more efficient than the minimum standard), models that lost the Energy Star certification (15-19% more efficient than the minimum standard), and models that met the revised standard before and after the revision (at least 20% more efficient than the minimum standard.) In panels c) and d), prices of the 16 models that were decertified are compared to the prices of ENERGY STAR models that did not lose their certification.



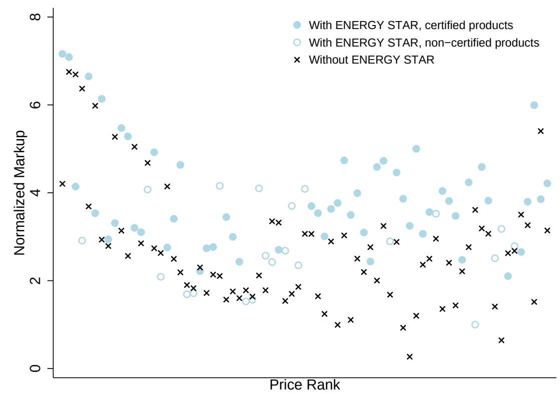
(a) Markups, Observed vs. Predicted



(b) Markups w vs. w/o ENERGY STAR, Predicted



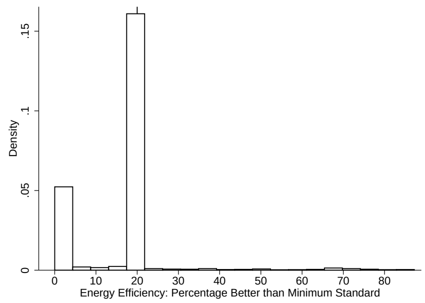
(c) Markups vs. Energy Efficiency, Predicted



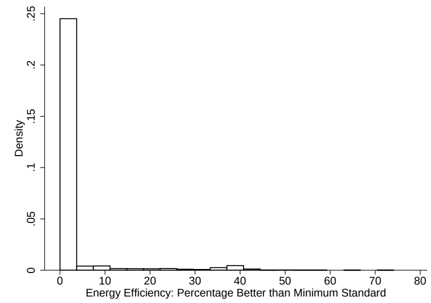
(d) Markups vs. Prices, Predicted

Figure 5. Markups

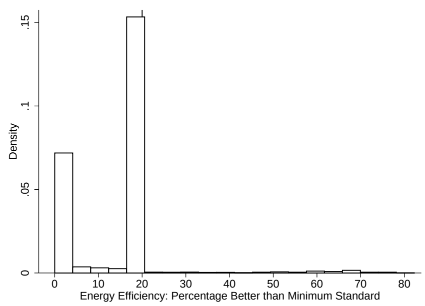
Notes: Each observation represents the normalized markup of a product included in the representative choice set. In Panel a, all percentage markups are normalized by dividing by the lowest observed markup. The observed percentage markup is the difference between the promotional and wholesale prices, divided by promotional price. Predicted markups are obtained from the simulation model. A value of one means that the percentage markup is exactly equal to the lowest percentage markup observed in the retailer data. In Panels b, c, and d, the percentage markups are normalized by dividing by the lowest markup predicted when ENERGY STAR is in effect. Panel b shows that predicted markups in a market without ENERGY STAR are smaller than in market with ENERGY STAR. Panel c shows that when ENERGY STAR is not in effect, the three products with the largest markups are also the most energy efficient. In Panel d, lower price ranks correspond to lower prices. Panel d shows that the cheapest products have the highest percentage markups.



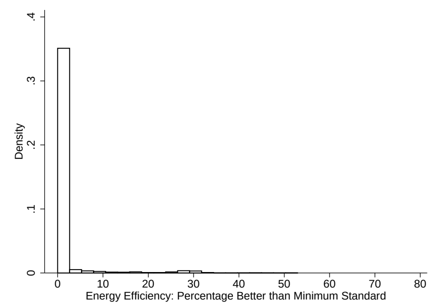
(a) w ENERGY STAR, $\phi = 451$



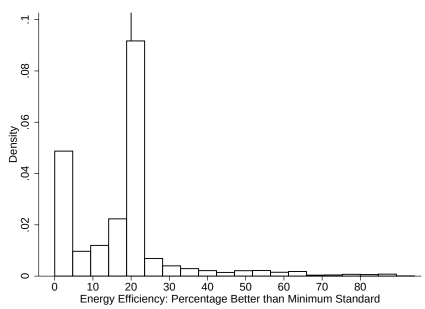
(b) w/o ENERGY STAR, $\phi = 451$



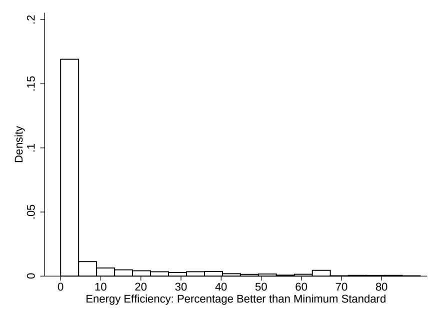
(c) w ENERGY STAR, $\phi = 650$



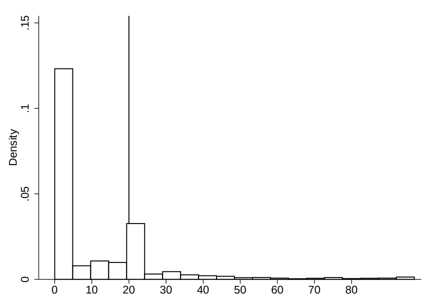
(d) w/o ENERGY STAR, $\phi = 650$



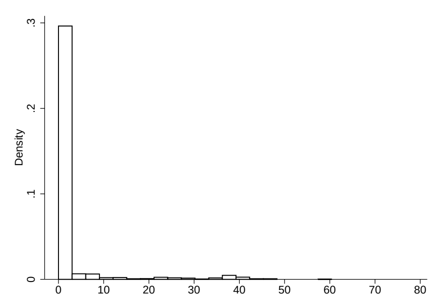
(e) w ENERGY STAR, $\phi = 150$



(f) w/o ENERGY STAR, $\phi = 150$

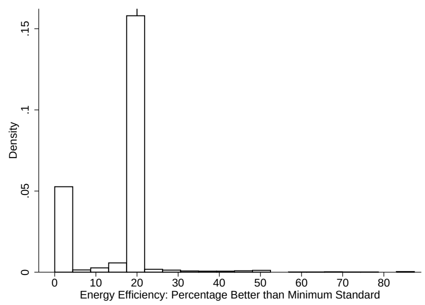


(g) w ENERGY STAR, $\phi = 451$, Small Label Effect

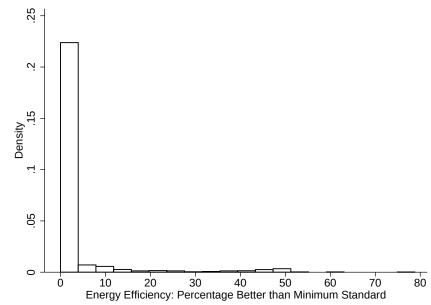


(h) w/o ENERGY STAR, $\phi = 451$, Small Label Effect

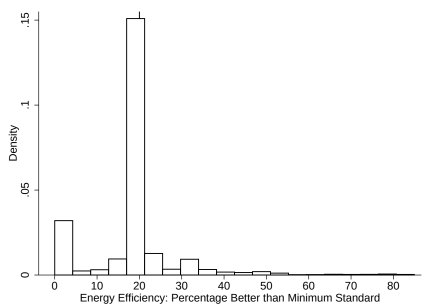
Figure 6. Energy Efficiency Offered, With and Without ENERGY STAR



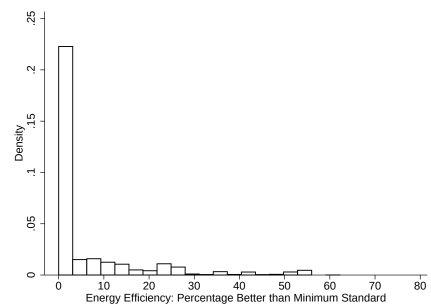
(a) w ENERGY STAR, w/o Externalities



(b) w/o ENERGY STAR, w/o Externalities

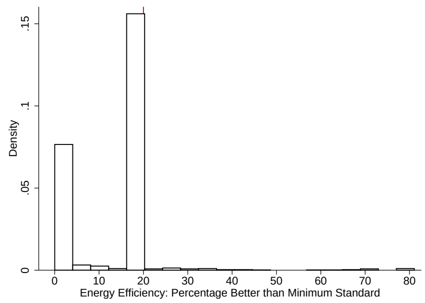


(c) w ENERGY STAR, Low Share Uninformed Consumers

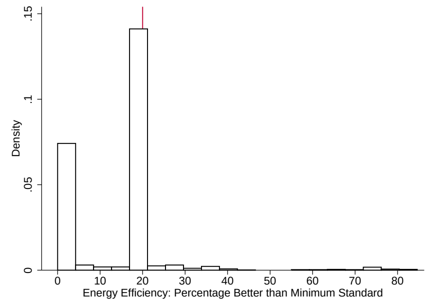


(d) w/o ENERGY STAR, Low Share Uninformed Consumers

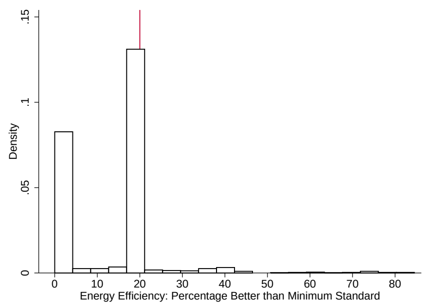
Figure 7. Energy Efficiency Offered, With and Without ENERGY STAR



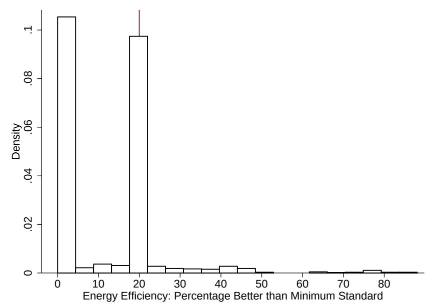
(a) 7.5 cents/kWh



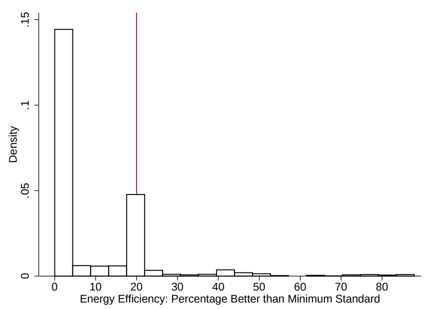
(b) 10.0 cents/kWh



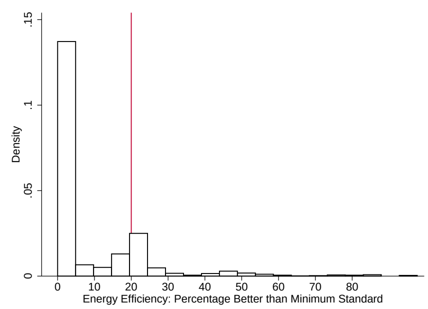
(c) 12.5 cents/kWh



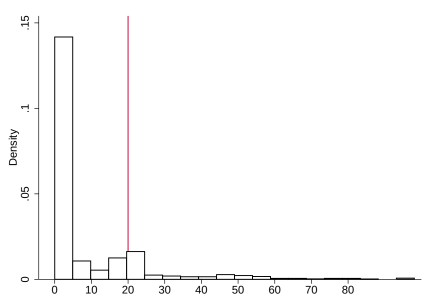
(d) 15.0 cents/kWh



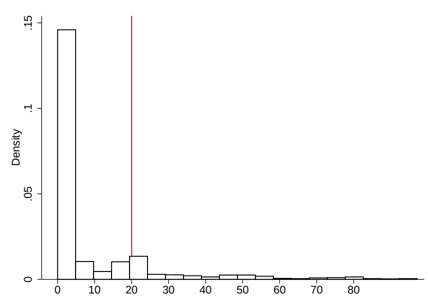
(e) 17.5 cents/kWh



(f) 20.0 cents/kWh



(g) 17.5 cents/kWh



(h) 20.0 cents/kWh

Figure 8. Energy Efficiency Offered, With ENERGY STAR and Different Electricity Prices

TABLE 1. Market Shares and Model Shares, US Refrigerator Market

	1995	2000	2005	2008
Manufacturer		Market Share		
GE	35%	34%	29%	27%
Electrolux	17%	21%	25%	23%
Whirlpool	27%	24%	25%	33%
Maytag	10%	14%	11%	-
Amana	10%	5%	0%	-
Haier	0%	0%	2%	6%
W.C. Wood	0%	0%	1%	1%
Others	1%	2%	7%	10%
Brand		Model Share		
Kenmore	8%	14%	17%	17%
GE	13%	7%	5%	8%
Kitchen Aid	5%	5%	6%	6%
Amana	8%	4%	3%	3%
Maytag	11%	16%	12%	9%
Whirlpool	7%	5%	10%	10%
Frigidaire	4%	17%	13%	12%
White-Westing.	4%	-	-	-
L G	-	-	3%	
Others	50%	36%	30%	27%

Sources: Appliance Magazine; data compiled by the Department of Energy (market share). California Energy Commission (CEC) Appliance Database (model share). Only full-size refrigerators models on the Californian market for each year are considered. Model shares correspond to the number of models, non-sales weighted, offered by each brand.

Table 2. Price Change After Decertification of Energy Star Models

	2008 Revision in Energy Star Standard		**2010 Revision in Certification**	
	MSRP	**Promo.**	**MSRP**	**Promo.**
	(I)	**(II)**	**(III)**	**(IV)**
	Dependent Var.: log(price)		Dependent Var.: log(price)	
$ESTAR$	0.046***	0.020***	0.045***	0.012
	(0.0039)	(0.0038)	(0.0051)	(0.0073)
Week FE	Yes	Yes	Yes	Yes
Product FE	Yes	Yes	Yes	Yes
Nb of Models	2,623	2,623	1,367	1,367
Nb of Decertified Models	1,334	1,055	16	16
Nb of Observations	130,914	130,914	57,601	57,601
Adjusted R^2	0.041	0.013	0.031	0.004

Notes: For specification I and II, refrigerator models that were not certified ENERGY STAR as of January 1^{st} 2008, models that were certified and met the more stringent standard, and models that lost their ENERGY STAR certification are considered. For models V-VIII, only refrigerator models that were certified ENERGY STAR as of January 1^{st} are considered. For 2008, I assume that the decertification of ENERGY STAR models occurred in the seventeenth week. For 2010, I assume that the decertification occurred in the fifth week. The dummy variable $ESTAR_{jt}$ takes the value one if a refrigerator is certified in week t. Standard errors are clustered at the product level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 3. Summary Statistics: US Refrigerator Market

Price	
Avg Promotion	11%
Avg Duration of a Promotion	7.6 days
Avg Price Paid (2008)	$1114
SD Price Paid (2008)	$625
Electricity Costs	
Avg Elec. Consumption of a Refrigerator	520 kWh/y
Avg Elec. Consumption: ENERGY STAR	500 kWh/y
Avg Elec. Consumption: Decertified ENERGY STAR 2008	520 kWh/y
Avg Elec. Consumption: Non-ENERGY STAR	576 kWh/y
Choice Set	
Nb of Refrigerator Models, US Market 2008	2,762
Nb of Decertified Refrigerator Models, US Market 2008	1,278
Nb of Refrigerator Models, Retailer's Sample	3424
Nb of Refrigerator Models, Demand Estimation	1013
Avg Size Choice Set, Demand Estimation (Store-Month)	133
SD Size of Choice Set (Store-Month)	60
Choice Set: Cost Estimation/Simulation	
Nb of Refrigerator Models	78
Brand	(%)
Brand A	10.0
Brand B	17.3
Brand C	41.3
Brand D	9.3
Generic Brand	24.0
Size	(%)
AV$<$ 23.5 cu. ft.	49.3
AV$\geq$ 23.5 cu. ft.	50.7
Refrigerator Style	(%)
Top Freezer	16.0
Side-by-Side	25.3
Bottom-Freezer	58.7
ENERGY STAR Certification	(%)
No	29.3
Yes	70.7

Notes: The sample used for the demand estimation consists of all transactions made by homeowners living in single family housing units that bought no more than one refrigerator in the year 2008. The number of full-size refrigerator models for the whole US was obtained from the US EPA. According to the FTC data, there were 2,693 full-size refrigerators offered on the US market in 2008.

Table 4. Cost Estimation

	Structural Estimator	Matching Estimator
ϕ	451	362†
		(208)
Cost Elasticity: $\frac{\partial c(f)}{\partial kWh}\frac{kWh}{c(f)}$	0.82	0.66
Nb of Product Lines	78	78
Nb of Products	78	155

Notes: For the structural estimator, a grid search is performed to find the value that optimizes the objective function. The matching estimator takes the wholesale price as the dependent variable. For each matched refrigerator model, only one wholesale price is observed. The dependent variable is the inverse of the annual electricity consumption of each product. Product line fixed effects are included. Dummies for color are also included, none of them are statistically significant. Models that have the same size, style, brand, door material (stainless or not), ice-maker option, defrost technology, and entered the market the same year, share the same product line fixed effect. † $p < 0.10$,* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5. Demand Estimates

	Income <$50,000		**Income** ≥$50,000 & <$100,000		**Income** ≥$100,000	
Behavioral Parameters Purchase Decision:						
Price (η)	-0.005	(1.2E-05)	-0.004	(7.5E-06)	-0.004	(6.7E-06)
Label Effect, $e = F$ (τ^F)	-0.150	(0.041)	0.064	(0.017)	-0.027	(0.028)
Label Effect, $e = ES$ (τ^{ES})	0.259	(0.021)	0.248	(0.017)	0.567	(0.044)
Rebate (π)	0.002	(0.0005)	0.001	(0.0003)	0.001	(0.0003)
Elec. Cost (θ)	-0.040	(0.003)	-0.034	(0.001)	-0.043	(0.002)
Behavioral Parameters Latent Probabilities:						
K^h	-10.28	(4.20)	-9.10	(1.57)	-7.31	(0.702)
K^m	0.179	(4.07)	1.80	(2.18)	-1.67	(1.10)
β^F_{educ2}	0.079	(1.08)	0.156	(0.479)	-0.166	(0.211)
β^F_{educ3}	-3.96	(1.94)	1.22	(0.703)	10.03	(0.286)
$\beta^F_{fam-size}$	0.285	(0.308)	0.948	(0.170)	0.064	(0.053)
β^F_{age}	0.955	(0.057)	0.187	(0.027)	0.158	(0.012)
β^{ES}_{educ2}	0.074	(1.04)	0.137	(0.564)	-0.187	(0.238)
β^{ES}_{educ3}	-3.28	(1.86)	0.194	(0.816)	10.10	(0.278)
$\beta^{ES}_{fam-size}$ 0.704	(0.299)	1.51	(0.187)	0.193	(0.058)	
β^{ES}_{age}	0.797	(0.054)	0.006	(0.030)	0.072	(0.013)
$mean - Elec$	-0.014	(0.010)	-0.014	(0.010)	0.008	(0.006)
$var - Elec$	0.049	(0.057)	-0.013	(0.062)	-0.066	(0.041)
$\gamma^F_{NbModels}$	-0.735	(0.035)	0.002	(0.008)	0.001	(0.003)
$mean - ES$	3.40	(1.22)	3.20	(0.919)	3.16	(0.477)
$var - ES$	-0.664	(1.78)	-8.14	(2.90)	-4.41	(1.56)
$\gamma^{ES}_{NbModels}$	-0.778	(0.034)	-0.018	(0.010)	-0.014	(0.003)
Interpretation						
Own-Price Elasticity	-6.35		-5.14		-4.28	
Implicit Discount Rate (%)	11.6		10.9		4.9	
WTP ES Label, $e = F$ ($)	-27		14		-7	
WTP ES Label, $e = ES$ ($)	47		56		154	
Prob. Take Rebate (%):	29.0		21.9		14.7	
$Q(e = F)$	32.2		41.4		44.5	
$Q(e = ES)$	2.21		48.2		40.4	
$Q(e = U)$	65.6		10.4		15.1	
Nb Obs.	49,279		76,114		76,114	

Notes: In the estimation, estimated product fixed effects enter the individual choice probabilities, and are treated as data. Standard errors are obtained using the Murphy and Topel's approach (1985).

TABLE 6. Emission Factors and Externality Costs

Non-baseload Output Emission Rates (U.S. Average)			
Pollutant	Estimate		Source
$CO2$	1,583 lb/MWh		
$CH4^a$	35.8 lb/GWh		
$N2O^a$	19.9 lb/GWh		USEPA, eGRID2007
$SO2$	6.13 lb/MWh		
NOx	2.21 lb/MWh		
Damage Cost (2008 $)			
Pollutant	Low Estimate	High Estimate	Source
$CO2$	$21.8/t	$67.1/t	Greenstone, Kopits, and Wolverton (2011)
$SO2$	$2,060/t	$6,700/t	low: Muller and Mendelsohn (2012), high: USEPA[b]
NOx	$380/t	$4,591/t	low: Muller and Mendelsohn (2012), high: DOE[c]

Notes: (a) Externality costs associated to $CH4$ and $N2O$ are assumed to be the same than for $CO2$. $CH4$ and $N2O$ are converted in CO2 equivalent using estimates of global warming potential (GWP). The GWP used for $CH4$ is 25, and the GWP used for $N2O$ is 298. Source: IPCC Fourth Assessment Report: Climate Change 2007. (b) Estimate used in the illustrative analysis of the 2012 regulatory impact analysis for the proposed standards for electric utility generating units. (c) Higher value of the estimate used in the Federal Rule for new minimum energy-efficiency standards for refrigerators (1904-AB79).

Table 7. The Effects of Removing the ENERGY STAR Certification

	Main Estimates		**Firms Bunch at Minimum**		**Sensitivity Tests**					
					High Marginal Cost		Low Marginal Cost		Low Label Effect	
	I	II	III	IV	V	VI	VII	VIII	IX	X
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
kWh Purchased (kWh/year)	43	12	104	14	48	16	-11	29	-15	28
Externality Costs (M$/year)	31	9	74	10	34	11	-8	21	-11	20
Consumer Surplus (M$/year)	28	16	-10	18	39	15	10	31	13	12
Profits (M$/year)	-886	115	-976	141	-864	168	-450	428	-82	327
GVT Revenues (M$/year)	-	-	-	-	-	-	-	-	-	-
Total Welfare (M$/year)	-889	127	-1061	154	-859	187	-433	423	-57	344

Notes: The table reports the difference between a market without and with ENERGY STAR. The counterfactual scenario is the market without ENERGY STAR. A negative sign implies that removing ENERGY STAR leads to a decrease in a particular metric relative to a market with ENERGY STAR. The model is bootstrapped 100 times. The mean and standard deviation of the difference in various metrics are reported. Columns I and II are the main estimates. They suggest that removing ENERGY STAR decrease total welfare, but most of the decrease comes from a reduction in profits. Columns III and IV report estimates assuming that firms will bunch exclusively at the minimum standard without ENERGY STAR. Columns 5-10 are sensitivity tests. Increasing the marginal cost of providing energy efficiency increases the relative benefit of ENERGY STAR. Decreasing the marginal cost has the opposite effect. For a low label effect, the effect on profits is much smaller relative to other scenarios. When the marginal cost or the label effect are low, removing ENERGY STAR leads to a decrease in electricity consumption.

Table 8. ENERGY STAR Certification and Interactions with Market Failures

	Main Estimates		**Interaction Pigouvian Tax**		**Low Share Uninformed**	
	I	II	III	IV	V	VI
	Mean	Std	Mean	Std	Mean	Std
kWh Purchased (kWh/year)	43	12	34	17	-12	28
Externality Costs (M$/year)	31	9	24	12	-8	20
Consumer Surplus (M$/year)	28	16	-15	22	27	28
Profits (M$/year)	-886	115	-748	137	-493	187
GVT Revenues (M$/year)	-	-	24	12	-	-
Total Welfare (M$/year)	-889	127	-764	142	-457	203

Notes: The first two columns are the same main estimates reported in Table 7. In columns 3 and 4, a Pigouvian Tax of $0.079/kWh is added to the price of electricity. This reduces the relative impact of the ENERGY STAR program. In column 5 and 6, the share of uniformed consumers is fixed at 4% for all income groups. Under this scenario, ENERGY STAR increases electricity consumption, on average.

Table 9. Optimal Certification Requirement

Requirement w.r.t. Minimum Standard	kWh Purchased (kWh/year)	Externality Costs (M$/year)	Profits (M$/year)	Consumer Surplus (M$/year)	Total Welfare (M$/year)
5%	-2	-2	-49	1209	1161
10%	-16	-11	-45	1207	1173
15%	-29	-21	-36	1022	1007
20%	-43	-31	-28	886	889
25%	-57	-41	-14	772	799
30%	-33	-24	-14	384	393
35%	5	4	-25	65	36
40%	10	7	-17	45	21
45%	7	5	-5	45	35
50%	29	21	-9	-50	-80

Notes: Each estimate is the mean of the difference between a market with certification versus without certification. Positive numbers mean that ENERGY STAR leads to an increase. 50 bootstrap iterations were performed for each increment of the certification requirement. Profits are maximized when the certification requirement is set at 5%, which means that certified products must consume less than 95% electricity than the minimum standard. Externality costs are minimized when the certification requirement is set at 25%. Consumer surplus and externality costs are jointly maximized when the certification requirement is set at 25%.