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Working Paper 18/290
May 2018

Economics Working Paper Series

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

The Incidence of Coarse Certification: Evidence from the ENERGY STAR Program

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May 22, 2018

Abstract

A coarse certification provides simple, but incomplete information about quality. Its main rationale is to help consumers trade off dimensions of quality that are complex and lack salience. In imperfectly competitive markets, it may induce excess bunching at the certification requirement, crowd out high quality, and facilitate price discrimination. Who will ultimately benefit from a coarse certification thus depends on the degree of market power firms can exercise as well as on consumers' sophistication in responding to such information. This paper illustrates these insights using the ENERGY STAR certification program as a case study. I investigate the incidence of the program with a structural econometric model of the U.S. appliance market. I find that the certification can crowd out energy efficiency, make consumers worst off, and have small, but heterogenous impacts on firms' profits. In this context, the certification tends to not be welfare-improving. This conclusion, however, crucially depends on the market environment and the design of the policy—in scenarios where energy prices are low, or the certification requirement is very stringent, the ES program can be welfare-improving.

JEL: D43, L13, L15, L68, Q48.
Keywords: Coarse certification, consumer attention, differentiated markets, structural estimation, energy efficiency.

*ETH Zürich, E2e Project, e-mail: shoude@ethz.ch. I would like to thank Wesley Hartmann, Tomomichi Amano, Jonathan Levin, James Sweeney, Louis-Gäetan Giraudet, Massimo Filippini, Ginger Zhe Jin, Christopher Timmins, Shanjun Li, and several seminar participants for helpful suggestions and comments. This research is part of the activities of SCCER CREST, which is financially supported by the Swiss Commission for Technology and Innovation (CTI).

The role of certification is to correct informational market failures when a dimension of quality is hard to assess. In practice, certification programs established by governmental entities, non-profit organizations, or trade associations offer a limited amount of hard information, but instead provide coarse signals. For instance, a certification often takes the form of a letter-grade system, star rating, or discrete numerical scale.[1] Coarse certifications are ubiquitous in the financial, health, real-estate, food, and energy sectors, among many others.

The main rationale of a coarse certification is to provide a simple heuristic to compare products. It is often managed like a brand with the aim of increasing the salience of one dimension of quality. When successful in branding, a coarse certification program then dictates the equilibrium in the market: consumers have a high willingness to pay for certified products and firms respond by offering products that meet the certification requirement. Ultimately, it may increase the provision of the hard-to-asses dimension of quality.

The coarse nature of a certification, however, can lead to unintended consequences. When a certification program complements readily available information that is accurate, but complex, it may crowd out efforts to rely on more accurate information signals (Houde 2017). Taking into account the strategic behavior of firms, this in turn may induce excess bunching at the certification requirement, distort prices, and crowd out the quality that the certification aims to increase in the first place.

Who ultimately benefits from a coarse certification thus depends on the degree of market power firms can exercise as well as on the share of sophisticated consumers that responds to such an information signal. This paper illustrates these insights using the ENERGY STAR (ES) certification program as a case study. I investigate the incidence of the program with a structural econometric model of the U.S. appliance market.

The analysis proceeds in three steps. I first develop a theoretical framework that provides intuition on why the welfare effects and the incidence of a coarse certification are a priori ambiguous. The framework formalizes that the incidence of a coarse certification depends on the degree of market power and heterogeneity in consumer sophistication. I then apply the framework to the energy domain to investigate the ES program, one of the most well-known environmental certifications

[1] To illustrate, credit rating agencies use letters to summarize asset risk, and online marketplaces commonly use star ratings as a measure of reputation.

used in the U.S. and Europe.[2] The goal of this program is to favor the adoption of energy-efficient products by providing simple and salient information to consumers. I develop a stylized oligopoly model of the U.S. refrigerator market and carry out a structural estimation with rich micro data. This allows me to simulate the market with and without certification to quantify the welfare effects associated with ES for different market participants.

In my main policy simulation, I find that ES crowds out the provision of energy efficiency and reduces welfare. Consumers are better off without certification and this holds across income groups and regions subject to low and high electricity prices. High-income households living in regions with high electricity prices gain the most without certification because a large share of products offered exceeds the certification requirement and these households tend to value energy efficiency more. Firms tend to benefit from the certification, but the effect on profits is small and heterogeneous. These results crucially depend on various features of the market environment. The crowding-out of energy efficiency occurs because there is a large-enough share of consumers that would respond to energy costs information in the absence of certification. Therefore, firms find it optimal to offer products with higher efficiency levels that largely exceed the certification requirement that was in effect. In the absence of certification, the share of products that meet the federal minimum energy efficiency standard also increase, which intensifies price competition in this region of the product space, and benefits consumers that value energy efficiency less. More generally, the degree of market power firms hold, the electricity prices, and the share of sophisticated consumers impact not only the magnitude, but also the direction of the welfare effects. I also show that a more stringent certification requirement could have made ES welfare-improving in my context. Those are important conclusions. Given that the ES certification is rolled out on a technology-by-technology basis, the regulator has the ability to adjust the certification to the market environment in order to yield a desirable outcome.

Although ES is one of the main federal policies used in the U.S. to manage energy demand and it has been adopted in several countries, this paper is the first to conduct a comprehensive welfare analysis of the program accounting for firm behavior and consumer heterogeneity. Prior work on ES has focused primarily on estimating how consumers value the certification (Houde 2017; Newell and Siikamäki 2014; Eichholtz, Kok, and Quigley 2010; Walls, Gerarden, Palmer, and Bak 2017;

[2]The ES program was first established in the U.S. in 1992, but since then it has been adopted in Canada, India, and several European countries.

Ward, Clark, Jensen, Yen, and Russell 2011).[3] These studies show that consumers' willingness to pay for ES is large, and may even exceed the monetary value of the energy savings associated with certified products.

This paper complements a large body of work on instrument choice for energy and environmental policy. Certification programs are a popular type of information-based policy used to account for environmental externalities. Several theoretical studies have investigated issues that arise in the design of environmental certifications, such as competing labels (Fischer and Lyon 2014; Heyes and Martin 2016), firms' strategic behaviors (Amacher, Koskela, and Ollikainen 2004), consumers' confusion (Harbaugh, Maxwell, and Roussillon 2011), and imperfect certification requirements (Mason 2011). An important take away from this literature is that environmental certifications are not guaranteed to improve welfare. Moreover, they even may have the unintended consequence of decreasing environmental quality (Kotchen 2006). I reach similar conclusions by focusing on the interaction between two market failures: imperfect competition and consumers' costly information acquisition, which I refer to as micro-frictions. In the presence of micro-frictions, the introduction of a coarse certification induces some consumers to rely on a coarse signal instead of a more accurate signal.[4] In equilibrium, this induces firms to offer fewer products that exceed the certification requirement and can lead to an overall decrease in quality. I refer to this phenomenon as the crowding-out effect. Welfare is also impacted by distortions in prices due to imperfect competition. I show that a coarse certification segments the market in one dimension of quality, which relaxes price competition and leads to higher markups. Moreover, a salient certification that succeeds in creating a brand effect facilitates second-degree price discrimination when a share of consumers has a large willingness to pay for certified products, which also helps firms to maintain larger markups.

My work is also related to studies that have focused on the car market and investigated manufacturers' strategic response to environmental regulations, especially fuel economy standards (e.g., Reynaert and Sallee 2016; Ito and Sallee 2017; Whitefoot, Fowlie, and Skerlos 2017; Holland, Hughes, and Knittel 2009; Klier and Linn 2012; Jacobsen 2013; Knittel 2011). The general consensus from these studies is that mandatory minimum standards reduce profits and are dominated by

[3]Allcott and Sweeney (2016) payed attention to the role of the supply side by studying the behavior of sales agents offering ES-certified products. They found that sales agents were selectively choosing to offer ES-certified products for different consumers.

[4]In my empirical model, I propose a rational model of attention allocation in the spirit of Sims (2003) and Sallee (2014) to capture consumers trading off coarse information versus accurate, but more costly information. Alternative behavioral models could also be used to model this trade-off (e.g., Mullainathan, Schwartzstein, and Shleifer 2008).

market-based instruments. The present paper focuses on a different market, but more importantly on a different use of standards. The fact that ES acts as a voluntary standard and induces innovation beyond a minimum standard is an important distinction and explains why (some) firms may benefit from such certification.

This paper contributes more broadly to the literature on certifications and information disclosure programs. An important theme in this literature is whether a certification can be informative and mitigate adverse selection problems as in Akerlof (1970). A large strand of this literature studies the behavior of sellers and buyers subject to information asymmetries, where the sellers decide to self-certify. In these models, certification acts as a signaling device that usually does not provide full information (Stahl and Strausz 2017). I also study a certification that is not fully informative. However, in my setting, the coarse information does not arise from the strategic signaling motive of the sellers (e.g., Goel and Thakor 2015), but is instead a design decision made by the regulator. In this setting, I highlight the mechanisms by which a coarse certification—providing some relevant information—might not necessarily succeed in increasing the provision of a hard-to-assess dimension of quality and ultimately welfare. Finally, I also focus on linking the theoretical framework to an empirical setting to conduct an empirical welfare analysis of a certification program, which has remained surprisingly scarce in this literature (Dranove and Jin 2010).

The remainder of the paper is organized as follows. The next section presents a general framework to study the welfare effects of coarse certifications in imperfectly competitive markets. Section 2 discusses the empirical setting. Sections 3 and 4 develop and estimate an oligopoly model of the U.S. appliance market. The policy analysis is performed in Section 5, and conclusions follow.

1. Coarse Certification and Imperfect Competition

1.1. Set-Up

I will first consider a monopolistic market for a product for which consumers have unit demand. The product is a technology that has a dimension of quality that is hard to assess by consumers, because information is shrouded and hard to collect, and/or complex and hard to process. I assume that consumers are heterogeneous with respect to their ability to collect and process information. To fix ideas, the technology could be an energy intensive durable (e.g., a car, a refrigerator, or a television) and the hard-to-assess dimension of quality could be the lifetime energy operating costs.

The utility of consumer i from purchasing product j is modeled as follows:

$$U_{ij} = \theta_i a_j + \delta_j - p_j \tag{1}$$

where a_j is the hard-to-assess attribute, δ_j represents preferences for other dimensions of quality, and p_j is the price. θ_i is a behavioral parameter that captures heterogeneity in consumers' abilities to collect and process information and form accurate beliefs. Underlying θ_i is a process where various micro-frictions impact how consumers evaluate the attribute a.[5] To keep the exposition simple, I focus on the case where θ_i is a random variable with a binary distribution that represents the probability that consumer i lacks the sophistication to asses the attribute a and simply dismisses it, or is sophisticated and values a with a marginal valuation of γ_i. The probability that consumer i is unsophisticated versus sophisticated is denoted $h_i(U)$ and $h_i(I)$, respectively. θ_i is thus defined as follows

$$\theta_i = \begin{cases} 0, & \text{with probability } \; h_i(U) \\ \gamma_i, & \text{with probability } \; h_i(I) = 1 - h_i(U) \end{cases} \tag{2}$$

In this framework, there is an important conceptual distinction between the parameter γ_i and the parameter θ_i. Whereas γ_i represents preferences and captures the utility that a consumer experiences upon purchasing a product; θ_i, on the other hand, represents decision utility at the time of purchase. The difference between γ_i and θ_i thus produces a gap between decision and experienced utility—i.e., the utility a consumer expects to experience ex ante versus the utility that is actually experienced ex post (Kahneman, Wakker, and Sarin 1997).

Both γ_i and h_i vary among the population of consumers, but the firm does not have good prior information on γ_i or h_i. Instead, the firm simply knows the realization of θ_i for some segments of the population. Much of the intuition can be derived for the case where the firm has prior beliefs for two segments such that $\theta_i = \{\theta_L, \theta_H\}$, where $\theta_L < \theta_H$, and π is the prior that consumers are of type L. This scenario could represents the case where the monopolist knows the share of low versus high-income consumers, together with the beliefs that low-income consumers tend to be more inattentive and have a low marginal valuation for the attribute a (i.e., they have a high value of $h_i(U)$, but a low value of γ_i), relative to high-income consumers. I assume that the latent probabilities h_i and valuations γ_i $\forall i$ are not impacted by the firm strategy. The behavioral parameters θ_L and θ_H are

[5] There are several behavioral models that can provide the micro-foundations to model such a process. In the empirical application, I propose a rational model of search with heterogeneity in the cost of collecting and processing information, which leads to discrete types with respect to the degree of sophistication with which consumers respond to the hard-to-assess attribute. Other micro-frictions, such as biased beliefs, can also explain why consumers would not consider or misperceive attribute a.

thus fixed from the standpoint of the firm. Finally, I assume that the cost to produce attribute a is increasing and convex, and denoted $C(a)$.

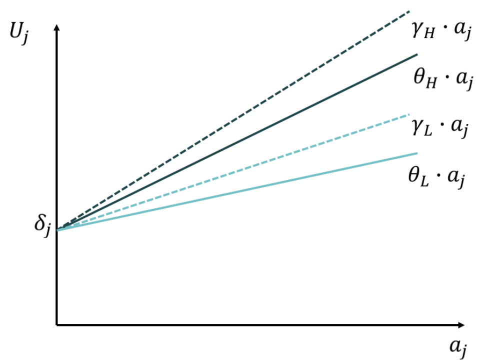
Under this set-up, there are three market failures at play: imperfect competition, asymmetry of information between the firm and consumers, and micro-frictions, which induce different levels of consumer sophistication. The monopolist's optimal choice for the level of the attribute a and the price offered to each consumer segment is the solution of the canonical screening problem of Mussa and Rosen (1978). The social planner's solution, however, differs due to the gap between decision and experienced utility induced by the micro-frictions. As illustrated on Figure 1, the social planner will address the three market failures at once by setting the level of a_i for each consumer type such that the marginal cost of producing attribute a equals the true (i.e., the experienced) marginal valuation: $C'(a_i) = \gamma_i$.

The monopolist's strategy is based upon her beliefs about consumers' decision utility: in particular the realization of θ_H and θ_L. The firm can distort quality to screen consumers[6] and sets $C'(a_H) = \theta_H$ and $C'(a_L) = \frac{\theta_L-(1-\pi)\theta_H}{\pi}$ (see Appendix A for a derivation). Because $\theta_H < \gamma_H$, and the cost is increasing with a, a_H will be under-provided relative to the social optimum. This is an important difference from the classic screening problem, where only quality for the lower type is distorted. In the presence case, the monopolist will thus under-provide quality at both ends of the quality spectrum (Panel d, Figure 1). For the high type, the distortion in quality arises because of the micro-frictions and firm' inability to differentiate consumers subject to differ levels of micro-frictions. For the the low type, the distortion in quality is the combined effect of the three market failures: imperfect competition, asymmetry of information, and micro-frictions.

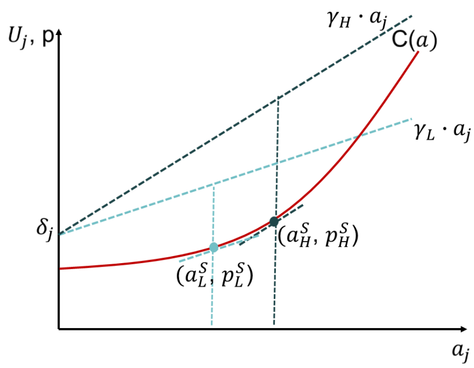
1.2. **Coarse Certification**

I model a coarse certification as follows. I assume that it provides a simple and salient information signal about the value of a. The coarse information signal impacts the purchase decision via two mechanisms. First, the certification can be informative and provide a heuristic to assess the value of a. In such case, consumers might form beliefs about the average value of a for certified products versus non-certified products. Consumers may thus value certified products, which I note $D_j = 1$, as function of the difference in the conditional means of a: $E[a|D_j = 1] - E[a|D_j = 0] = \bar{\tau}_i$.

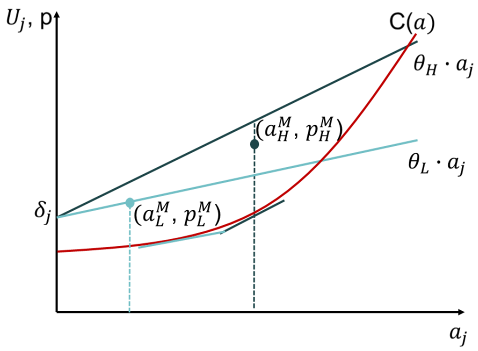
[6]If θ_L is small relative to θ_H, there might not be a solution for the optimal level offered to type L consumers. In such case, the firm might simply set a at its minimum: $a_L^* = \underline{a}$, or offer only one product (pooling equilibrium). Therefore, there are two possible equilibria: a separating equilibrium and a pooling equilibrium.



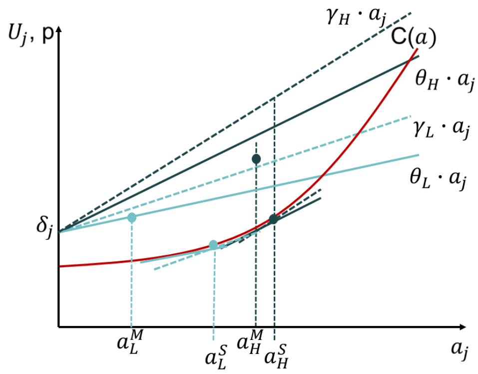
(a) Consumer Utility: Experienced vs. Decision Utility



(b) Social Outcome



(c) Monopoly Outcome



(d) Monopoly vs. Social

FIGURE 1. Equilibrium Outcomes without Certification

Notes: Panel a shows consumer utility for good j without a coarse certification. Experienced utility is depicted by the dashed lines, and decision utility is depicted by the solid lines. In Panel b, the social outcome corresponds to the points where the experienced marginal valuations equal the marginal cost. The monopoly outcome (Panel c) is the solution of the standard screening problem of Mussa and Rosen (1978), except that the monopolist considers consumers' decision utility. Relative to the social outcome, the monopolist under-provides quality to the low type and the high type (Panel d).

Second, the certification, similar to some type of advertising, might be persuasive (Bagwell 2007) and impacts preferences directly, irrespective of the level of a. I will be agnostic on the nature of the behavioral mechanisms leading to persuasion, and simply assume that if a is a desirable attribute, $\tilde{\tau}_i \geq 0$ is the persuasion effect.

The informative nature of the coarse certification will also impact the degree of sophistication with which consumers assess the attribute a, and, thus, the underlying latent probabilities determining the parameter θ_i. Consumers can now fall in three categories: with probability $\hat{h}_i(C)$, a consumer will rely on the coarse certification; with probability $\hat{h}_i(U)$, a consumer will remain unsophisticated; and with probability $\hat{h}_i(I)$, a consumer will be sophisticated.

As before, I assume that the firm does not have good prior information on h_i and γ_i. In addition, the firm has beliefs about $\tau_i = \bar{\tau}_i \hat{h}_i(C) + \tilde{\tau}_i$, but not specifically about $\bar{\tau}_i$ and $\tilde{\tau}_i$. The consumer utility can now be expressed as:

$$U_{ij} = \hat{\theta}_i a_j + \tau_i D_j + \delta_j - p_j \tag{3}$$

where D_j takes a value of one if product j is certified and zero otherwise, and

$$\hat{\theta}_i = \begin{cases} 0, & \text{with probability } \hat{h}_i(U) \\ \gamma_i, & \text{with probability } \hat{h}_i(I) = 1 - \hat{h}_i(U) - \hat{h}_i(C) \end{cases} \tag{4}$$

In Equation 3, the coarse certification impacts utility by creating a discrete increase of size τ_i in the willingness to pay for certified technologies and by changing the marginal valuation of the hard-to-assess attribute from θ_i to $\hat{\theta}_i$. Note that $\theta_i \geq \hat{\theta}_i$ if the certification changes the shares of unsophisticated and sophisticated consumers as follows: $h_i(U)$ becomes $\hat{h}_i(U) \leq h_i(U)$ and $h_i(I)$ becomes $\hat{h}_i(I) \leq h_i(I)$. The first inequality is intuitive. Some consumers might find it too difficult to fully assess the attribute a, but can process the coarse information signal. Therefore, when a certification is introduced, some consumers that used to dismiss a completely, now account for it using the heuristic provided by the certification. The second inequality captures the fact that a coarse certification might allow some consumers to economize on efforts required to assess a. In such case, the certification crowds out the share of better informed consumers toward a share of consumers that rely on the simpler, but coarser information signal (Houde 2017). When this latter phenomenon occurs, the following inequality holds: $\theta_i > \hat{\theta}_i$, which has important implications for determining the equilibrium outcomes under a coarse certification.

Figure 2 (Panel a) illustrates the two mechanisms. At the certification requirement, denoted a^C, the marginal valuation of a increases by τ_i, but for any other values of a, the marginal valuation decreases: θ_i becomes $\hat{\theta}_i$, where $\theta_i > \hat{\theta}_i$, due to the crowding out of informed consumers. In a separating equilibrium, the level of a offered to the high type, which is determined by the equality

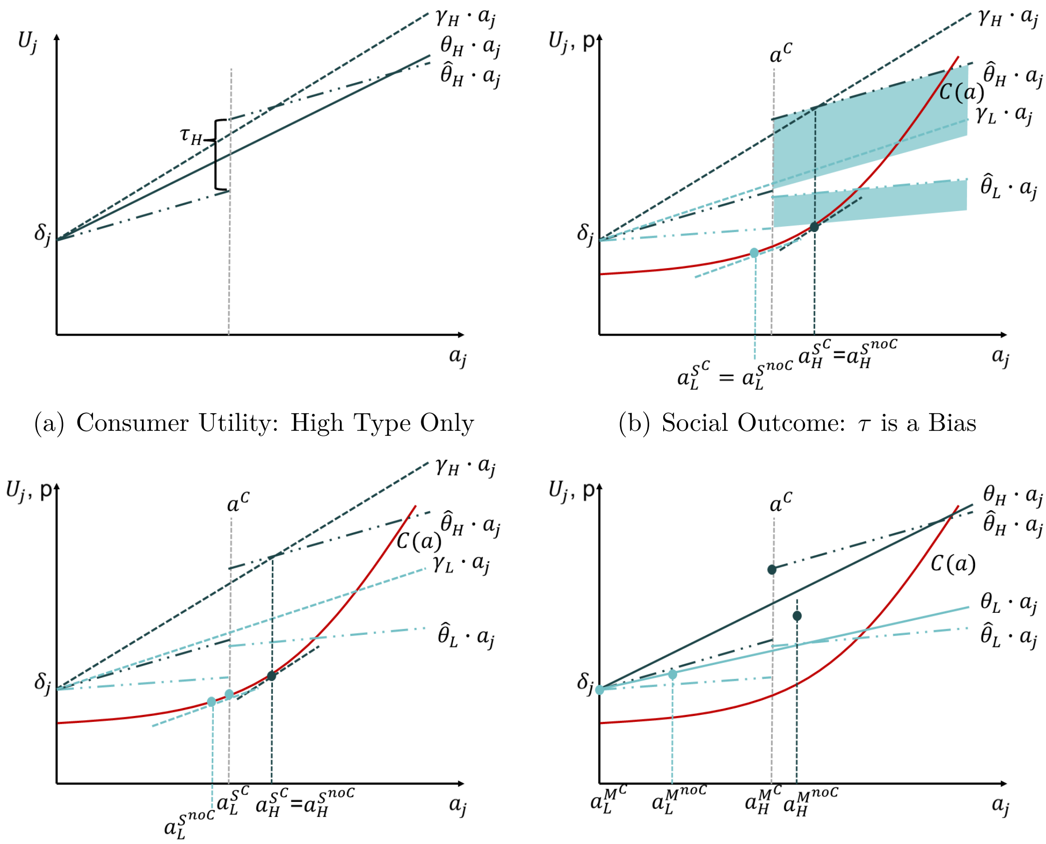
$\hat{\theta}_i = C'(a_H^*)$, can thus decrease (Panel d). The large discontinuity at the certification requirement also implies that the monopolist might want to set $a_H^* = a^C$, although $\hat{\theta}_i < C'(a^C)$. The coarse certification can thus distort product lines by inducing bunching at the certification requirement. Whether bunching at the certification is socially desirable or not will depend on the welfare interpretation of the parameter τ_i. If τ is considered a bias that impacts consumers' decisions, but should not be accounted for in social welfare, bunching at a^C is not socially desirable (Panel b). If τ is considered as preferences and represents the utility gains induced by the certification that are truly experienced, the social planner might find optimal to set quality at the certification requirement (Panel c). As I show formally in the Appendix A, the impact of bunching on the overall provision of a is uncertain relative to a market without certification. For instance, if without certification $a_H^* < a^C$, but with certification $a_H^* = a^C$, the coarse certification increases the provision of a. But, it is possible that without certification $a_H^* > a^C$, and the certification induces $a_H^* = a^C$. This latter case is illustrated on Panel d of Figure 2—the bunching at the certification crowds out the overall provision of a.

1.3. **Multiple Firms**

In the presence of multiple firms, the coarse certification will also affect the level of a purchased in equilibrium due to its effect on price competition. In imperfectly competitive markets, the introduction of a certification impacts prices via two distinct mechanisms: the segmentation effect and differentiation effect (Bonroy and Constantatos 2014).

The segmentation effect arises when the certification induces a separating equilibrium where both certified and non-certified products are offered, which creates localized markets in the product space. As the density of the products decreases in the different dimensions of the characteristic space due to the segmentation, this softens price competition and enables firms to exercise more market power. A coarse certification should impact prices via the segmentation effect as the certification requirement creates a focal point to segment the market in the dimension of the hard-to-assess attribute.

The differentiation effect arises due to the heterogeneous impact of the certification on consumers' valuations of a. Formally, the asymmetric impact of the certification across consumer types will relax or tighten the set of incentive compatibility constraints faced by firms, which will ultimately impact the equilibrium prices. For instance, the fact that some consumer types might



(a) Consumer Utility: High Type Only

(b) Social Outcome: τ is a Bias

(c) Social Outcome: τ is Preference

(d) Monopoly Outcome with Crowding-Out

FIGURE 2. Equilibrium Outcomes with and without a Coarse Certification

Notes: Panel a illustrates how consumer's utility (high type only) for good j changes with a coarse certification. The certification creates a discontinuous jump in the valuation of a at the certification requirement a^C and lowers the marginal valuation at all other values of a. The social outcomes with certification, denoted with the superscript S^C, and without certification, denoted with the superscript S^{noC}, are shown on panels b and c. Panel b represents the case where the discontinuous jump in decision utility induced by the certification τ is a bias. Panel c represents the case where τ corresponds to preferences. The monopolist outcomes with and without certification are shown on Panel d for a case where bunching at the requirement a^C is optimal and crowds out of low and hight quality occurs.

respond strongly to a coarse certification, i.e., have a large latent share $h_i(C)$ together with a large τ_i, might facilitate price differentiation and lead to higher mark-ups.

Whereas the segmentation and differentiation effects are closely interrelated, the first is a function of the number of products in various regions of the characteristic space, and the second is a function of the heterogeneity in how much consumers value the hard-to-assess attribute. Both of these effects, together with the extent of the crowding effect, will ultimately determine the incidence of a coarse certification on the different market participants.

1.4. **Interactions with Negative Externalities**

So far, I have not discussed the case where the hard-to-assess attribute could also be associated with externalities. To illustrate, suppose that increasing the level of a leads to a decrease in negative externalities. In the presence of such externalities, there is an additional rationale to use a policy to increase the level of a set by the monopolist. A coarse certification is, however, not guaranteed to improve economic efficiency when micro-frictions, imperfect competition, and asymmetry of information are also present. Due to the interactions of these latter three market failures, the certification can crowd out lose$a$, which would then exacerbate externalities. s

1.5. **The Incidence of Coarse Certification**

To determine the incidence of a coarse certification it is crucial to understand the reallocation of the hard-to-assess attribute, a, in the characteristic space. When the certification crowds out the provision of quality, consumers that purchased a high level of this attribute in a market without certification are the ones that will be the most negatively impacted. In particular, sophisticated consumers with a high marginal valuation γ_i will lose the most if crowding out occurs. The relative share of sophisticated versus unsophisticated consumers across consumer segments will determine whether firms want to differentiate their products in the hard-to-assess dimension. As more consumers become sophisticated, this will provide incentive to the firms to offer high level of quality a. By offering a larger number of products at high level of a, this will intensify price competition in region of the product space with higher quality. All those effects should contribute to make sophisticated/high marginal valuation consumers better off.

If in the absence of certification, firms offer a larger number of products with a low level of quality a, this will increase the price competition in this region of the characteristic space. As a result, consumers with the lowest marginal valuation for a will benefit. Put another way, these consumers might lose the most from the introduction of a certification if it induces firms to reduce the number of low quality products on the market.

Firms will benefit from the certification if it enables them to exercise more market power, the extent of which will be determined by the magnitude of the segmentation and differentiation effects induced by the reallocation of a in the product space. Generally, the market structure and the amount of market power each firm holds pre-certification will be important determinants of the incidence across firms for a particular certification program.

2. Empirical Setting: The U.S. Refrigerator Market

I focus on the U.S. refrigerator market, which offers several advantages to study the ES program. First, this market is subject to an array of government policies that interact with ES, which provides both credible variation for the estimation and a relevant institutional context. Second, refrigerators are one of the few energy-intensive durables that have large energy operating costs, but for which utilization decision may not need to be explicitly modeled. The fact that the (unobserved) utilization is likely to be idiosyncratic and not systematically correlated with the purchase decision facilitates the identification of preferences related to energy efficiency. Third, refrigerators are relative simple technologies, which have not been subject to important innovation trends during my sample period. Again, this simplifies the estimation and identification of preferences, and notably motivates my static framework. Finally, the U.S. refrigerator market, like for several other types of energy-intensive durables, is an oligopolistic market where the effects of imperfect competition have been found to be important (Ashenfelter, Hosken, and Weinberg 2013).

2.1. Government Policies

In the U.S., like in many other countries, government agencies have established certification programs to favor the adoption of energy-efficient appliances. The main rationale of such programs is that energy efficiency, in particular, the lifetime energy operating cost of an appliance, is difficult to assess and not fully salient to consumers. A certification that provides a simple and salient information signal can then play a role in helping consumers easily identify the most energy-efficient products on the marketplace, and ultimately induce firms to offer and advertise such products.

The ENERGY STAR (ES) program—a voluntary certification that was first established by the U.S. Environmental Protection Agency (EPA) in 1992—exemplifies how these programs work. The U.S. Government sets certification requirements, and products that meet or exceed the requirements can be certified with the ES label (Figure 3(a)). The label consists of a simple logo that does not contain technical information. The certification requirements for ES are usually binary—products are ES labelled or not. Therefore, the ES label only provides a coarse signal about energy efficiency. In Japan, China, India, and Europe, the design of energy labels rely on a similar approach, where a coarse star or letter grade system is used to provide information about energy operating costs.

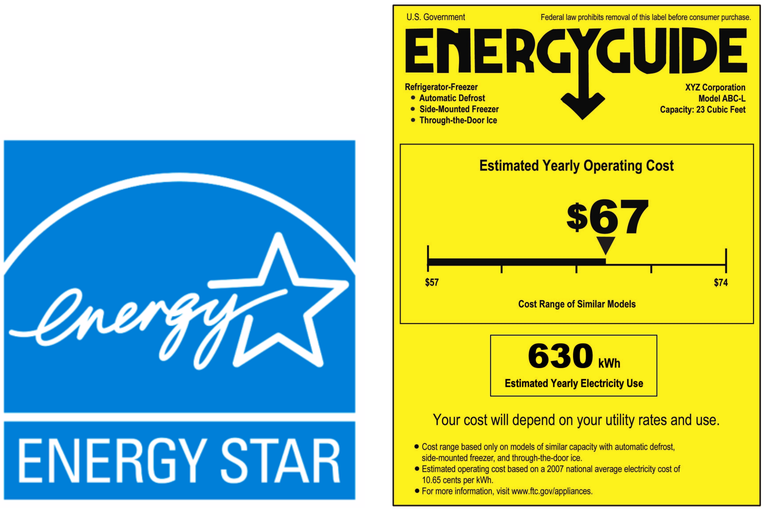
In the U.S. refrigerator market, technical information is also provided to consumers by the EnergyGuide label (Figure 3(b)). Unlike the ES program, EnergyGuide is a mandatory labeling program that provides detailed model-specific information about energy operating costs. In the U.S. context, consumers thus face two pieces of information to account for energy operating costs. In Houde (2017), I have shown that, although the two energy labels were designed to complement each other, they are in fact substitutes. In particular, consumers that tend to rely on the ES certification do not rely on EnergyGuide and vice-versa. A significant share of consumers also appear to not rely on either of these pieces of information. I have also shown that consumers that rely on ES tend to value the ES label beyond the average energy savings determined by the certification requirement. Altogether, these findings point toward the existence of different types of consumers in this market that differ in the degree of sophistication to account for energy information.

The high willingness to pay for the certification suggests that the ES label may affect preferences directly by providing warm glow and conformity with social norms, or by enacting purely altruistic motives. It is also possible that the label biases the perception of quality. For instance, consumers might believe, wrongfully, that certified models are of higher quality, a phenomenon referred to as the halo effect (Boatwright, Kalra, and Zhang 2008).

Apart from informing consumers, the ES certification program also plays an important role in the design of energy efficiency subsidies. In the U.S., there exist several consumer rebate programs that explicitly target the adoption of ES-certified appliances. The effect of these incentives on consumers' purchase behavior tends to be highly heterogeneous across different segments of the population and program designs (Houde and Aldy 2017a,b). Rebate programs contribute in making ES an important focal point of firms' product lines, pricing, and advertising strategies.

2.2. **Market Structure**

The U.S. refrigerator market has an oligopolistic market structure dominated by three manufacturers: Electrolux, General Electric (GE), and Whirpool. Several mergers and acquisitions that have taken place since the early eighties, culminating with Whirlpool's acquisition of Maytag in 2006, led to a concentrated market. In 2008, the three dominant manufacturers held about 85% of the market share for full-size refrigerators (Table 1, Appendix B). Since then, a number of events may



(a) ES Label (b) EnergyGuide Label

FIGURE 3. ENERGY STAR (ES) and EnergyGuide Labels

have led to an increase in competition. In 2016, the GE appliance business got acquired by the Chinese manufacturer Haier, while Korean appliance manufacturers have steadily gained market shares.

A particular institutional feature of the U.S. appliance market is that manufacturers compete under various brand names, and some dominant brands, such as Kenmore, are not owned by a particular manufacturer, but are sold exclusively by a national retailer. This feature of the market is believed to be important in determining the degree of market power manufacturers ultimately hold. The distribution of products across brands is still, however, fairly concentrated, especially after the Whirlpool-Maytag merger; most products were offered by the major brands associated to the top three manufacturers and Kenmore (Table 1, Appendix B).

2.3. Data

The empirical investigation focusses on the U.S. market for full-size refrigerators during the period 2008-2011. The main data source consists of point-of-sale data provided by a national appliance retailer. The data are disaggregated at the transaction level and contain information on the price and taxes paid by consumers, the wholesale price paid by the retailer, the location of the store where each purchase was made, and the manufacturer model number. I used the manufacturer model number to match the transaction data with detailed attribute information, which include manufacturers' reported yearly energy usage, ES certification, size, color, door design, brand, and manufacturer, in addition to several other attributes. The attribute data contain information about all refrigerator models offered by the retailer during the period 1998-2011. Only a subset of these models are observed during the period 2008-2011 and thus used for the demand estimation. For approximately 40% of the transactions, I also observe consumer-specific demographic information, which includes income level, education, single vs. multifamily housing, owner vs. renter status, family size, age of the head of the household, and political orientation. The demographic information was collected by the retailer using the services of a data aggregator and matched with each transaction, whenever possible.

To complement the data from the national retailer, I also collected information about local electricity prices from the Energy Information Administration (Form EIA-861) and rebates (DSIRE database). For the demand estimation, I constructed local averages at the county level for both variables and impute the county of residence for each consumer assuming that a consumer lived in the same county as the store where the purchase was made.

Finally, I used data from the Federal Trade Commission and the EPA to determine which refrigerator models were on the market during the period 2008-2011. I use this information in the supply-side estimation to construct a representative choice-set of the U.S. refrigerator market during that period.

3. Econometric Model

I characterize the appliance market with a static multi-product oligopoly model 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 in prices and product lines. The decisions to enter and exit the market, and to determine the size of product lines and the quality of non-energy attributes are taken as given. The demand side is modeled as in Houde (2017), where consumers are heterogeneous along two dimensions: income, which is observable, and sophistication in their ability to process energy information, which is unobservable.

3.1. Supply

I model the vertical structure of the industry in a stylized way by making abstraction of the strategic interactions between manufacturers, national retailers, and local store managers. I focus on modeling the behavior of brand managers, where each brand manager represents a firm that maximizes the profits of his own brand across retail stores. This characterization of the supply-side captures the fact that manufacturers offer similar products under different brand names. In this model, a product line decision consists of acquiring appliance models through procurement contracts with manufacturers; and brand managers' unit costs are the retail wholesale prices charged by manufacturers and the retail costs. I assume that the wholesale prices, which I observe, are equal to the manufacturers' marginal cost of producing one unit of a particular refrigerator model. This is a realistic assumption if we assume that the retailer, brand manager and manufacturer respectively selling, marketing, and manufacturing a model are fully integrated (Berto Villas-Boas 2007), or the manufacturer uses a two-part fee structure in its vertical contract relationship with the retailer (Bonnet and Dubois 2010).

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 ES requirement; manufacturers systematically managed to offer new products that were more energy-efficient, but were otherwise similar to previous generations.[7] 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 wholesale prices reflect this assumption.

Under these assumptions, 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 $Q_{kj}(f, p)$, and depends on all energy efficiency levels and prices ($f = \{f_1, ..., f_K\}$ and $p = \{p_1, ..., p_K\}$). The problem of brand manager k consists of solving:

$$\max_{\substack{f_k=\{f_{k1},...,f_{kJ_k}\},\\ p_k=\{p_{k1},...,p_{kJ_k}\}}} = \sum_{j=1}^{J_k} (p_{kj} - c^w_{kj}(f_{kj}) - c^r_j) \cdot Q_{kj}(f, p)$$

[7]Interestingly, when the EPA announced in April 2007 that the ES requirement 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 more stringent requirement. Ultimately, most manufacturers were, however, able to offer new models meeting the 2008 requirement within a year of the date that the EPA made the announcement.

where $c^w_{kj}(f_{kj})$ is the manufacturing cost of model j offered by brand k that varies as a function of the energy efficiency level. The term c^r_j represents a model-specific unit retail cost, which may capture advertising expenses, inventory costs, or warranty liabilities, but do not vary with the energy efficiency level offered.

3.2. **Demand**

The demand model follows closely the set-up in Section 1 and provides a theory to explain heterogeneity in the way consumers account for a hard-to-assess attribute, namely energy efficiency. At the heart of the model is heterogeneity in the costs of collecting and processing energy information, which leads to different consumer types with respect to the way each type accounts for energy efficiency in their purchase decisions. In particular, these costs rationalize why some consumers either dismiss the energy efficiency attribute or rely on ES, although accurate, but more complex information about energy costs is readily available in this decision environment.

The purchase decision is modeled as a two-step process, where consumers first select the amount of energy information they want to collect and process, and then make a purchase decision. The decision to collect and process energy information is treated as a latent decision. The choice model thus takes the form of a discrete latent class model:

$$Q_{irt}(j) = \sum_{e=\{U,ES,I\}} H_i(e) \cdot P^e_{irt}(j), \tag{5}$$

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 ES certification. They can be knowledgeable about ES ($e = ES$), but not about the exact energy cost of each product. Finally, they can be fully informed ($e = I$) and know the energy cost of each product in their choice set. $H_i(e)$ is the probability that consumer i acquires knowledge e, and $P^e_{irt}(j)$ is the choice probability conditional on the level of knowledge. $Q_{irt}(j)$ is then the overall choice probability for product j. In the estimation, the choice probabilities are computed for each household i, and are region and time specific, which are denoted by the subscripts r and t, respectively. The alternative-specific utilities that enter the conditional choice probabilities $P_{irt}^{e}(j)$ for each type e are:

$$\text{e=I:} \quad U_{ijrt}^{I} = -\eta P_{jrt} + \delta_j + \psi R_{rt} X D_{jt} - \theta C_{jr} + \epsilon_{ijrt}^{I}$$

$$\text{e=ES:} \quad U_{ijrt}^{ES} = -\eta P_{jrt} + \delta_j + \psi R_{rt} X D_{jt} + \tau D_{jt} - \theta ESavings_r X D_{jt} + \epsilon_{ijrt}^{ES}$$

$$\text{e=U:} \quad U_{ijrt}^{U} = -\eta P_{jrt} + \delta_j + \epsilon_{ijrt}^{U},$$

where P_{jrt} is the price, δ_j is the quality of the product, R_{rt} is the rebate amount offered for ES products, and D_{jt} takes the value one if product j is certified ES at time t and zero otherwise. The difference in alternative-specific utility for informed consumers ($e = I$) and consumers relying on ES ($e = ES$) is twofold. Informed consumers consider an accurate measure of annual energy operating costs, the variable C_{jr}, which is the product of the local electricity price, the county average in region r, and manufacturer's reported annual electricity usage for model j. If consumers rely on ES ($e = ES$), they instead simply compute the average energy cost savings associated with the certification, the variable $ESavings_r$, which is the difference between the average annual electricity usage of certified models and non-certified models multiplied by the local electricity price. The second difference is that for $e = ES$, the ES label itself could impact the decision, where the parameter τ captures the behavioral response to the label. The label effect could capture preferences for green good, warm glow, but also various behavioral biases induced by the certification. For uniformed consumers (e=U), I assume that they dismiss all information related to energy use; not only they dismiss energy operating costs, but they are also not aware of the rebates offered for ES-certified models. Finally, ϵ_{ijrt} is an idiosyncratic taste parameter. Assuming that the idiosyncratic taste parameters ϵ are extreme value distributed, the probabilities P_{irt}^{e} take the form of a multinomial logit.

In Houde (2017), I discuss the micro-foundations to model the latent probabilities $H_{irt}(e)$. In a nutshell, costs of collecting and processing information together with a fixed number of decision strategies to account for energy efficiency in the purchase decision give rise to different consumer types. The latent probabilities are then function of variables that impact how difficult it is to compare refrigerator models in the energy dimension. For the estimation, they are specified as follows:

$$H_{irt}(e) = \frac{e^{V_{irt}(e)}}{\sum_k e^{V_{irt}(k)}} \tag{6}$$

with

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

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 a consumer's decision to collect energy information in a model of rational attention allocation (Sallee 2014), 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 ES models offered. Finally, $NbModels_{rt}$ is the number of models in the choice set in a given region.

3.3. **Equilibrium**

The Nash equilibrium of the game is given by the vectors f^* and p^* that solve a system of $4 \times (J_1 + J_2 + ...J_K)$ equations. For each firm k, the first order conditions are:

(I. F.O.C. pricing)
$$Q_{kl}(f^*, p^*) + \sum_{j=1}^{J_k} (p^*_{kj} - c^w_{kj}(f^*_{kj}) - c^r_j) \cdot \frac{\partial Q_{kj}(f^*, p^*)}{\partial p^*_{kl}} = 0,$$

(II. F.O.C. efficiency)
$$\mathbf{1}\{\pi(f_{kl}, f^*_{k,-l}, p^*_k) > \pi(f^{ES}_{kl}, f^*_{k,-l}, p^*_k) | \forall f_{kl}\} \times \left[Q_{kl}(f^*, p^*) \frac{dc^w_{kl}(f^*_{kl})}{df_{kl}} - \sum_{j=1}^{J_k} (p^*_{kj} - c_{kj}(f^*_{kj}) - c^r_j) \cdot \frac{\partial Q_{kj}(f^*, p^*)}{\partial f_{kl}} = 0 \right],$$

(III. Bunching at ES)
$$\mathbf{1}\{\pi(f_{kl}, f^*_{k,-l}, p^*_k) \leq \pi(f^{ES}, f^*_{k,-l}, p^*_k) | \forall f_{kl}\} \times \left[f^*_{kl} = f^{ES} \right],$$

for all $l \in J_k$ and k

(IV. Constraint minimum efficiency)
$$f_{kl} \geq \underline{\mathrm{f}}$$

for all $l \in J_k$ and k

In the second and third conditions (equations II and III, respectively), the indicator function arises because the demand function is not continuous at the certification requirement, denoted 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 requirement implies that it may not be optimal to equate the marginal cost of providing energy efficiency with the marginal valuation. In the presence of ES, firms' strategies then become a discrete-continuous choice where firms must 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.

4. Estimation

The focus of this section is on the cost estimation, and especially the identification of the marginal cost of providing energy efficiency and the unit retail costs. I provide a succinct overview of the demand estimation and refer the readers to Houde (2017) for further details.

4.1. Marginal Cost of Providing Energy Efficiency

The first goal of the cost estimation is to identify the marginal cost of providing energy efficiency, which allows me to endogenize product lines in this dimension. One challenge in identifying this cost is that the first-order conditions of the oligopolistic game with respect to energy efficiency levels are not well-defined due to the presence of the coarse ES certification. My identification strategy takes advantage of an institutional feature of the U.S. refrigerator market that allows me to recover the marginal cost with minimal assumptions about the nature of the strategic interaction between firms.

In the U.S., refrigerator manufacturers commonly offer product lines that consist of a group of three to ten refrigerator models with a similar design, such as the size and door style (top freezer, side-by-side, bottom-freezer), but that differ with respect to less prominent attributes, such as the ice-maker option, the finish option (stainless or not), the color, and, in some cases, the energy efficiency levels. In some instances, it is possible to observe different refrigerator models, within a given product line, that are identical along all dimensions of quality, except their energy efficiency levels. When it occurs, one model typically meets that ES certification requirement, or a previous requirement, and another just meets the minimum standards. These product line decisions are consistent with a screening equilibrium where firms use energy efficiency to differentiate their products, and are also induced by the way the ES certification requirement is revised. More stringent ES requirements do not follow a pre-determined schedule and are usually announced only one year in advance. Manufacturers must then adapt quickly to a change in the ES requirement. In practice, they often do so by making small incremental changes to their product design to achieve energy efficiency improvements.

For instance, in 2004 and 2008, the ES requirement for full-size refrigerator was adjusted to become more stringent—prior to 2004, it was set at 10% more efficient than the minimum standard; for the 2004-2008 period, it was 15%; and it became 20% after April of 2008. Manufacturers adjusted their product lines quickly in response to these revisions. In particular, we observe that following the revision of the ES requirement in 2004 and 2008, manufacturers responded not only by offering new models that met the revised standard, but also by discontinuing models that were decertified (Figure 1, Appendix B). This entry and exit of models around revision periods led to several instances of product lines where manufacturers offered the exact same models, but only differentiated in the energy dimension. In my sample, I was able to identify 51 identical pairs of refrigerator models that differ only with respect to their annual electricity consumption—a measure of energy efficiency reported by manufacturers. To identify those identical pairs, I first used detailed attribute data to find product lines offered by the same brand, where models where of the same size,[8] door style, door material (stainless or not), ice-maker option, defrost technology, air filtration system, color, and door handle type. For each of those pairs, information from online marketplaces was also collected to compare whether all listed attributed, except for energy use, were identical. After this process, the remaining sample contains 102 refrigerator models that could be paired with an identical model. Note that within each pair, the year that a specific model entered the market may differ.

Table 1 provides summary statistics on these paired refrigerators and compares them to the overall sample of models I observe in the retailer's data. On average, these refrigerator models tend to be cheaper, smaller, and more energy-efficient than the average refrigerator model offered on the market.

For all paired refrigerator models ($N = 102$), I simply exploit variation in energy efficiency level within pair group ($G = 51$) together with the fact that I observe wholesale price to identify the marginal cost of providing energy efficiency. I assume that the wholesale prices corresponds to the manufacturers' marginal unit costs and estimate the marginal cost by regressing the log

[8]The size attribute that I used includes a measure of freezer and refrigerator size. The height, width, and depth were also taken into account.

of the wholesale price on a pair fixed effect, year-of-market-entry dummies interacted with brand dummies, and a proxy for energy efficiency:

$$ln(price_{j,r}^{wholesale}) = \alpha + \gamma_{j,j'} + Y_j \times Brand_j + \phi Efficiency_j + \epsilon_{j,r}, \quad (8)$$

where $\gamma_{j,j'}$ is a pair fixed effect that is common to the paired refrigerator models j and j', and Y_j and $Brand_j$ are dummy variables for the year refrigerator j entered the market and its brand, respectively. These year-brand fixed effects account for various temporal shocks that might have affected the manufacturing process and thus prices at the moment a model entered the market. For the proxy for energy efficiency, I use a functional form where energy efficiency is defined as the inverse of the annual electricity consumption. I thus expect a positive coefficient for the estimate of the parameter ϕ, which will capture that more efficient models are costlier to produce.

For my preferred estimator, the parameter ϕ has a value of 191.1 (Table 1). This estimate implies that the wholesale price of a refrigerator model consuming 550 kWh/year will increase by 9.1% to meet the ES requirement, which corresponds to a cost elasticity with respect to energy efficiency of 0.45. This estimate is robust to different specifications: the controls for year-of-market-entry and brand have small effects.

4.2. **Retail Costs**

In addition to the manufacturing costs, brand managers are also facing various costs associated with retailing large appliances. These latter costs may include advertising, transportation and inventory, and warranty. Part of these retail costs might be sunk and fixed, but they may also vary with the quantity sold. For instance, online advertising expenses in this market vary with demand due to the fact that retailers effectively pay for adwords and clicks, which are correlated with quantity sold. I estimate the retail unit costs using the assumption that firms are profit maximizing and prices are set strategically. As it is standard in the literature, I use the first-order conditions of the pricing problem to recover the cost estimates. In particular, I use the following system of equations:

$$Q_{kl}(f^*, p^*) + \sum_{j=1}^{J_k} (p_{kj}^* - c_{kj}^w(f_{kj}^*) - c_j^r) \cdot \frac{\partial Q_{kj}(f^*, p^*)}{\partial p_{kl}^*} = 0, \forall f_{kl} \quad (9)$$

where both demand, $Q(\cdot)$, and the manufacturer costs, c^w, are taken as given, and I solve for c^r. In this market, it is not realistic to assume that the unit retail costs vary systematically across

Table 1. Paired Refrigerator Models: Summary Statistics and Estimation Results

	Paired Models	All Models
Summary Stats:		
# Models	102	6,859
MSRP ($)	1,073	1,671
kWh/y	493	575
Adjusted Volume (Cu. Ft.)	24	27
% more efficient than minimum (%)	11	10
Year entered on market	2004.8	2004.1
Estimation Marginal Cost Providing EE (ϕ): $ln(price^{wholesale}_{j,r}) = \alpha + \gamma_{j,j'} + Y_j \times Brand_j + \phi Efficiency_j + \epsilon_{j,r}$,		
Pair FE only	182.6	
	(55.5)	
Pair FE & Year-Brand FE	191.1	
	(67.5)	
Hedonic Regression	220.1	
	(97.5)	

Notes: The sample used to identify the identical pairs of refrigerator models contains all models offered by the retailer during the period 1998-2011. Only a subset of those models were used in the demand estimation. The summary statistics show that the paired refrigerator models tend to be smaller, cheaper and more efficient relative to the full sample. The estimation results for the parameter ϕ are reported for three specifications. The hedonic regression does not contain a paired fixed effect, but controls for the attributes used to identify the identical pairs: brand, size, door style, door material (stainless or not), ice-maker option, defrost technology, air filtration system, color, and door handle type. Standard errors are in parentheses.

refrigerator models. For instance, we should expect that a model offered by the same brand, of the same size, and at the same price point, should incur similar advertising expenses, have similar transportation and inventory costs, and face the same warranty liabilities. Therefore, I restrict unit retail costs to vary only along key dimensions of refrigerators that should be correlated with cost heterogeneity. In particular, I assume that they vary as a function of the brand, overall size, which is also a proxy for weight, door design, and price point. Crucially, I assume that retail costs do not vary as a function of energy efficiency.

To construct the empirical moments given by Equation 9, I need to characterize the market in terms of brands and products on the market. I assume that there are six different brands operating in the U.S. refrigerator market: the brands associated with the three main manufacturers, Kenmore, the Korean brands, and a generic brand that includes all other brands. Brands compete by placing their products at appliance stores. To reduce the dimensionality of the problem, I model the game for only one representative appliance store, which aims to represent the U.S. refrigerator market for the year 2011.[9] The size of the choice set is fixed at 68, and the number of refrigerators offered by each firm is held constant.[10] To ensure that the choice set is representative of the U.S. market, the distribution of the 68 products in terms of brand, style, size, and energy efficiency was selected to fit the distribution observed nationally in the year 2011. To illustrate, suppose that 5% of the full-size refrigerators available on the U.S. market in 2011 were GE top-freezer refrigerators with a size between 16 cu.ft. and 21 cu.ft., and certified ES. I sample 3 models in my sample (5% X $68 \approx 3$) that fit this description. To construct the choice set, I sample refrigerator models that were used in the demand estimation. This notably allows me to use the estimated product fixed effects to determine the location of each product in the quality dimension, which I hold fixed throughout the estimation and policy simulation. In Table 3 (Appendix B), I compare the constructed choice set with the observed choice set for the year 2011. There are some discrepancies. For instance, the constructed choice set has more models offered by Brand E and side-by-side refrigerators. But, in terms of energy efficiency and ES certification, which are more important attributes to assess the fit of my model, both choice sets are consistent.

The estimation results suggest that the average unit retail cost is $259, which leads to an average markup of 31.5% of the retail prices. There is, however, substantial variation across products. For instance, the retail costs for the largest refrigerator models are $77 higher relative to the smallest models. Across brands, the variation in retail costs can be as large as $249, holding all attributes constant. Overall, the estimates appear to be realistic and are consistent with other sources. For instance, my estimated markups are slightly more conservative than the markups used by the U.S. Department of Energy (DOE) to conduct their 2010 national impact analysis of minimum energy efficiency standards for refrigerators. The DOE then assumed that the retail markup was 37% of the final price.

[9]The year 2011 was chosen because it represents a year where firms seemed to have fully adjusted to the change in certification requirement that occurred in 2008.

[10]The size of the choice set corresponds approximately to half the number of models offered in a store in my sample. In my sample, the average number of refrigerator models offered by a store is 129 (Table 2, Appendix B). I set the size of the choice set to 68 for computational reasons. Qualitatively, the results for the supply-side estimation and the policy simulations are similar for larger choice sets.

4.3. **Demand**

The demand estimation is performed by forming the individual choice probabilities for each consumer, Q_{ijrt}, 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 subsamples of transactions were 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.

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

In Houde (2017), I discussed extensively the identification of the model. The sources of variation that I exploit are the following. Given that the retailer has a national pricing policy, I primarily rely on the temporal variation in prices to identify consumers' sensitivity to the purchase price.

I observe the same refrigerator models being sold at stores located in different electric utility territories and across time. This allows me to control for product fixed effects and to use cross-sectional and temporal variation in county-specific average electricity prices and rebates to identify the behavioral responses to these variables.

Following the revision of the ES standard for refrigerators in April 2008, a large number of refrigerator models lost their ES certification. 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 ES label. This variation in labeling can then be used to identify how consumers are influenced by the label.

Finally, heterogeneity in the way consumers process energy information and the parameters that enter the latent class probabilities (denoted $H_{irt}(e)$) are identified by substitution patterns that are induced by the change in relative prices, product entry and exit, and the ES decertification event.

Table 2 presents the parameter estimates 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. This latter conclusion hinges on two different effects.

Table 2. Information Acquisition Demand Model

	Income <$50,000		Income ≥$50,000 & <$100,000		Income ≥$100,000	
Behavioral Parameters Purchase Decision:						
Retail Price (η)	-0.413***	(0.0002)	-0.362***	(0.0001)	-0.317***	(0.0002)
ENERGY STAR τ^{ES}	0.674***	(0.001)	1.528***	(0.002)	1.365***	(0.080)
Rebate (ψ)	0.145***	(0.001)	0.090***	(0.0005)	0.033***	(0.0003)
Elec. Costs (θ)	-4.003***	(0.009)	-3.408***	(0.048)	-4.429***	(0.004)
K^I	1.357***	(0.0004)	0.974***	(0.004)	2.125***	(0.001)
K^{ES}	-6.441***	(0.023)	-5.011***	(0.025)	-3.056***	(0.070)
Educ: College (β_I)	-0.122***	(0.003)	0.691***	(0.014)	0.303***	(0.012)
Educ: Graduate (β_I)	1.717***	(0.031)	2.045***	(0.026)	1.197***	(0.032)
FamSize (β_I)	-0.204***	(0.0001)	-0.318***	(0.003)	-0.049***	(0.007)
Age (β_I)	0.092***	(0.0002)	0.084***	(0.002)	0.011***	(0.001)
Political: Democrats (β_I)	-1.284***	(0.022)	-1.899***	(0.034)	-0.221***	(0.025)
Political: Others (β_I)	-1.920***	(0.008)	-1.338***	(0.013)	-0.200	(0.018)
Educ: College (β_{ES})	-0.271***	(0.002)	0.012	(0.007)	0.105***	(0.007)
Educ : Graduate(β_{ES})	-0.453***	(0.014)	0.843***	(0.018)	0.676***	(0.028)
FamSize (β_{ES})	-0.193***	(0.002)	-0.091***	(0.001)	-0.232***	(0.014)
Age (β_{ES})	0.063***	(0.0002)	0.045***	(0.001)	0.024***	(0.001)
Political: Democrats (β_{ES})	-0.255***	(0.006)	-0.421***	(0.015)	-0.045	(0.024)
Political: Others (β_{ES})	-0.578***	(0.0003)	-0.469***	(0.009)	0.018	(0.025)
mean-ElecCost	0.107***	(0.003)	0.075**	(0.001)	0.105***	(0.008)
var-ElecCost	0.006***	(0.00002)	-0.101***	(0.001)	0.026***	(0.001)
# Models (γ^I)	0.007***	(0.0001)	0.012***	(0.0001)	0.004 ***	(0.0004)
Variance Price (γ^I)	-1.003***	(0.004)	-0.729***	(0.012)	-0.390***	(0.004)
Proportion-Estar	2.837***	(0.002)	0.975***	(0.001)	2.324***	(0.114)
# Models (γ^{ES})	-0.006***	(0.0002)	-0.001***	(0.0000)	-0.003***	(0.001)
Variance Price (γ^{ES})	0.316***	(0.004)	0.211***	(0.004)	0.109***	(0.006)
Interpretation						
Own-Price Elasticity	-5.36		-4.70		-4.12	
Implicit Discount Rate	0.08		0.08		0.03	
WTP ES Label ($)	163.43		422.22		430.33	
Prob. Taking Rebate	0.35		0.25		0.10	
$H(e = I)$	0.34		0.50		0.56	
$H(e = ES)$	0.21		0.10		0.17	
$H(e = U)$	0.45		0.41		0.27	
# Obs.	46,097		45,487		45,249	
LLE	188,088		194,394		195,969	

Notes: Asymptotic robust standard errors in parentheses: * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$). Prices, rebates, and electricity costs measured in hundreds of dollars. Average price of $1,300 used to compute own-price elasticity. Refrigerator lifetime of 18 years used to compute implicit discount rate.

First, the coefficient on electricity costs (θ), which captures the behavioral response to electricity costs for the share of informed consumers is smaller, in relative terms, for lower income households. To interpret the magnitude of the estimate of the sensitivity to electricity costs across income groups, I compare η and θ, and compute an implied discount rate that rationalizes how much consumers discount future electricity costs. To do so, I assume that consumers form time-unvarying expectations about annual electricity costs, and do not account for the effect of depreciation. Assuming a refrigerator lifetime of 18 years, the implied discount rate is 3% for households with an income larger than $100K, 8% for households with income between $50K and $100K, and 8% for households with income of less than $50K.

Second, lower income households are also more likely to dismiss energy information altogether. As shown by the latent probabilities, a significant share of consumers, across all income groups, have a high probability of being uninformed ($e = U$), but this probability is much higher for lower income group (45%) relative to the highest income (27%).

The share of consumers that pay attention to ES ($e = ES$) varies from 20% to 10% across income groups. For these consumers, the effect of the ES 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 $164 to $430. Those large willingness to pay estimates raise the question of whether the preferences for the ES label truly reflect consumers' preferences for certified models or biases in how consumers perceived the overall quality of certified models. As I discuss below, from a welfare standpoint, this is an important distinction to consider.

5. **Policy Analysis**

The main goal of the policy analysis is to create counterfactual scenarios with and without the ES certification. By comparing the market equilibrium for each of these two scenarios, I can assess the welfare changes and incidence of the program on different types of consumers, firms, and externalities associated with electricity consumption.[11]

[11] I do not take into account the change in government expenses associated with the program. According to the GAO (2011), the EPA spent an average of $57.4 M per year to run the ES program between 2008 and 2011. During this period, approximately 60 product categories were covered by the ES program. If I assume that the program costs are distributed proportionally across all product categories, an estimate of

5.1. **Set-Up**

For each policy simulation, I consider an oligopolistic structure that represents the national U.S. refrigerator market for the year 2011, which is the same choice set used for the supply-side estimation. I also consider alternative scenarios, where I increase the degree of market power of some firms.

Unless otherwise indicated, the ES requirement faced by firms is set to the level in effect in 2011, i.e., 20% relative to the minimum standard, and firms can certify refrigerator models that meet the requirement at no cost. For all scenarios, the demand model is simulated with a sample of households taken from the transactions used for the demand estimation. 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 county level. I set the rebate level for ES products to zero in all regions. Further details on the simulation procedure can be found in Appendix C.

To account for uncertainty in the demand and supply parameters, I perform the policy analysis by bootstrapping the equilibrium model. For each bootstrap iteration, I sample the demand parameters and the marginal cost of providing energy efficiency from their estimated distributions, and solve for the Nash equilibrium using the best-response iteration algorithm.

The framework used to characterize demand raises a number of issues for measuring consumer welfare. The two main challenges come from the fact that some consumers may make a purchase decision not fully informed, and the ES label might induce a bias in the perception of overall quality. Therefore, the utility experienced after the purchase decision may not be the same as decision utility, i.e., the utility a consumer anticipated at the time of a purchase.

the administrative costs of the program for the refrigerator market alone is \$0.96 M/year, which corresponds to less than \$0.10 per refrigerator sold.

In Houde (2017), I show that under the assumption that the decision utility of the informed consumer type coincides with experienced utility, the demand model provides a measure of compensating variation (CV) for a policy change $\mathcal{P} \rightarrow \tilde{\mathcal{P}}$ based on the concept of experienced utility:[12]

(10)

$$
\begin{aligned}
CV_i = \frac{1}{\eta}\Bigg\{ & \tilde{H}_i^I \cdot ln\sum_j^J exp(\tilde{U}_{ij}^I) - H_i^I \cdot ln\sum_j^J exp(U_{ij}^I) \\
& + \tilde{H}_i^{ES} \cdot \left[ln\sum_j^J exp(\tilde{U}_{ij}^{ES}) + \sum_j^J \tilde{P}_i^{ES}(\tilde{U}_{ij}^I - \tilde{U}_{ij}^{ES}) \right] - H_i^{ES} \cdot \left[ln\sum_j^J exp(U_{ij}^{ES}) + \sum_j^J P_i^{ES}(U_{ij}^I - U_{ij}^{ES}) \right] \\
& + \tilde{H}_i^U \cdot \left[ln\sum_j^J exp(\tilde{U}_{ij}^U) + \sum_j^J \tilde{P}_i^U(\tilde{U}_{ij}^I - \tilde{U}_{ij}^U) \right] - H_i^U \cdot \left[ln\sum_j^J exp(U_{ij}^U) + \sum_j^J P_i^U(U_{ij}^I - U_{ij}^U) \right] \Bigg\}.
\end{aligned}
$$

Applying the above formula to each income group, we can obtain an income-specific measure of CV, which takes into account the fact that some consumers may make a purchase decision without full information and subject to behavioral biases. This welfare measure departs from the standard expression for logit-based discrete choice models (Small and Rosen 1981) in two ways. First, it has the correction term $\sum_j^J P_i^{ES,U}(U_{ij}^I - U_{ij}^{ES,U})$, which captures the expected difference between experienced and decision utility for relying on the ES certification ($e = ES$), or for being uninformed ($e = U$), instead of being fully informed ($e = I$). This term captures the magnitude of the misperceptions due to imperfect information and behavioral biases. For the case where $e = ES$, the size of the misperception is partly induced by the label effect (parameter τ), which captures the large willingness to pay for certified models that goes well beyond average energy savings. In Equation 10, the parameter τ enters U_{ij}^{ES}, but does not enter not enter U_{ij}^I, which means that the label effect acts as a bias and does not impact experienced utility. Therefore, in a scenario without ES, consumer welfare will not mechanically decrease because the label is not present. My welfare measure thus provides a conservative estimate of the benefits consumers derive from ES.

The second difference between the expression in Equation 10 and the standard measure of welfare is that the overall CV is a weighted sum of the CV experienced by different latent consumer

[12]Leggett (2002) first showed how to derive an expression for CV with imperfect information in a discrete choice framework. Allcott (2013) derived a similar expression to measure welfare while accounting for consumer biases. Several recent applications also used a similar approach to perform a welfare analysis in the presence of behavioral biases, (e.g., Dubois, Griffith, and OConnell 2017; Ketcham, Kuminoff, and Powers 2016; Houde and Aldy 2017b).

types, where the weights are the probabilities H^e. The expression thus allows me to decompose the overall change in consumer welfare and report the incidence of a policy change on different types of consumers, although they are not readily observed. For instance, in the present application, I can report how uniformed versus informed consumers benefit/lose from the ES program.

Finally, to compute the externality costs associated with the electricity consumption of refrigerators, I 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 4 in Appendix B presents the emission factors and external damage costs I use. For the welfare calculations, I report two sets of results: one corresponding to the lower-end of the estimates of the externality costs, and another corresponding to the higher-end. These low/high estimates translate into an average external cost of \$0.024/kWh and \$0.079/kWh, respectively.

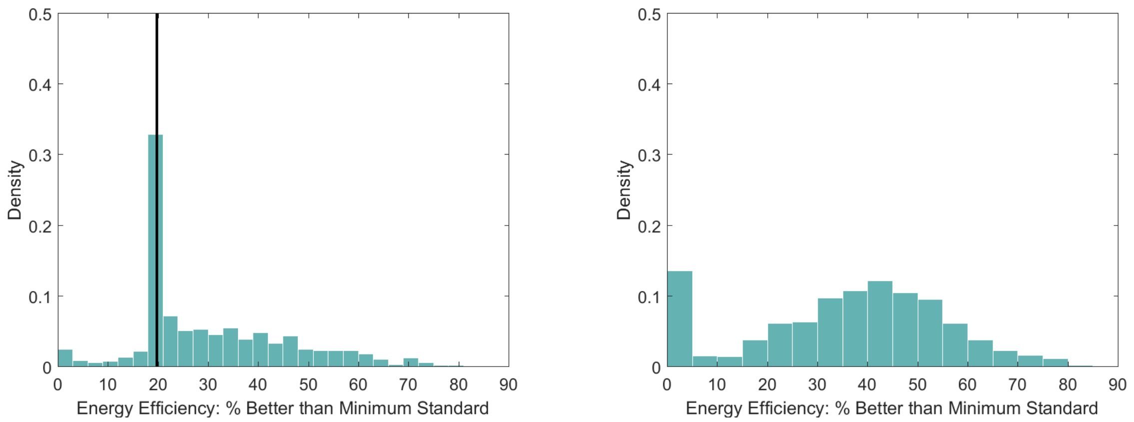
5.2. **Removing the ES Certification**

Figure 4 shows the distribution of energy efficiency with and without the ES certification. Panel (a) is the distribution predicted by the model when the ES requirement is 20% more stringent than the federal minimum standard.[13] The predicted distribution without the ES certification is presented in Panel (b). In the absence of the ES certification, firms offer a larger share of products, approximately 15%, that just meet the minimum standard, but, otherwise, the distribution shifts to the right, i.e., firms increase the efficiency levels of the remaining models. The predicted equilibrium

[13]Figure 2 in Appendix C (Panel a) compares the distribution observed in the representative choice set for the year 2011 and the simulated distribution. Overall, the model replicates well the excess bunching at the ES requirement. The simulation model predicts some products located at high energy efficiency levels, but those levels were not observed in the market in 2011. A number of reasons can explain this discrepancy. First, given that those efficiency levels are not observed, the estimation of the marginal cost of providing energy efficiency in this region of the product space is largely out of sample. I must then rely on the functional form assumption of the cost function to extrapolate the costs in this region. Second, the model is static and does not account for strategic interactions between the firms and the regulator. In a dynamic framework with such interactions, Amano (2017) demonstrates that firms may have an incentive retaining innovation, i.e., keep highly efficient models out of the market, to not signal to the regulator that they have the ability to innovate, which could lead to more stringent regulations.

without certification is thus consistent with a screening equilibrium with differentiation in the energy dimension.

Without certification, the average energy consumption of the models offered on the market decreases by 33.2 kWh/y relative to the market with certification (Table 3)—the ES certification thus crowds out the provision of energy efficiency. Taking into account the change in demand, removing the ES certification decreases the energy consumption by 35.7 kWh/y. This translates into a decrease ranging from $10 to $33 per consumer in the negative externalities associated with electricity consumption (Table 3).



(a) Predicted, with ES

(b) Predicted, without ES

FIGURE 4. Predicted Distribution of Energy Efficiency with and without Certification

Notes: Panels (a) presents the simulated distributions of products where the ES requirement is set at 20% more stringent than the federal minimum energy efficiency standard. In Panel (b), the model is simulated without the ES certification. Comparing panels (a) and (b), the model shows that the certification crowds out high efficiency models, but also removes a mass at the lowest efficiency level.

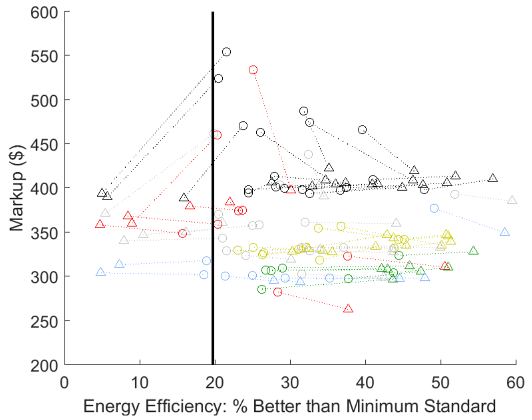
Removing the certification also increases consumer surplus and this holds across income groups. Consumers benefit in a market without ES for two reasons. First, ES distorts the allocation of energy efficiency by inducing excessive bunching at the requirement. Removing the certification reduces this distortion and firms offer energy efficiency levels that better match the distribution of consumer preferences.[14] Second, the ES certification also distorts pricing and helps firms maintain higher markups. Together, these two effects imply that removing the certification leads to more economically efficient pricing and product line decisions, which both benefit consumers. The magnitude of these effects is illustrated on Panel A of Figure 5, which shows the movement of each product in the energy efficiency dimension together with the changes in markups. We observe a large reduction in markups for products offered by Brand F (black) and Brand E (red), which are the firms that hold the most market power when ES is in effect. The reduction in markups is especially pronounced for ES products that were close to the certification requirement, but move toward the minimum standard.

For other firms, the change in energy efficiency is important, but the markups remain relatively unchanged. As a result, the average change in profits across firms induced by removing the certification is small—a gain of less than \$5/consumer (Table 3). This gain comes almost entirely from Brand F that benefits the most from having the certification removed, but this is an economically small gain: \$3.5/consumer. Without certification, the strategy of this firm is to capture the market for low efficiency products by decreasing markups, which leads to gains in market shares (Panel B, Figure 5). This contrasts with the strategies of other firms, which in the absence of ES maintain their markups, but tend to lose market shares.

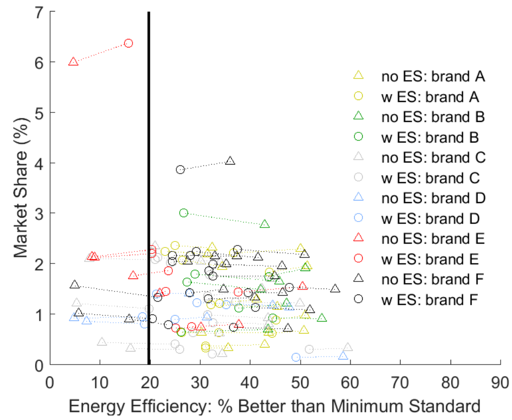
Across consumers, higher income consumers gain the most from having the certification removed. This is because, relative to the two other income groups, they have a larger share of informed consumers, and this share of informed consumers values energy efficiency more, as indicated by their low implicit discount rate. High income consumers are therefore the most negatively affected by the crowding-out effect and the resulting misallocation of energy efficiency induced by ES.

The crowding out of high-efficiency models also explains why informed consumers are better off in a market without certification relative to uninformed consumers. Informed consumers benefit when the distribution of energy efficiency offered matches their preferences, which are unlikely to be consistent with excess bunching at the ES requirement. Among uniformed consumers, low-income consumers benefit the most from the removal of ES (\$21/consumer). The fact that they tend to purchase cheaper refrigerators models that are subject to the largest price decreases explains this result.

[14] Due to the presence of imperfect competition, the provision of energy efficiency is, however, still distorted without ES. As in Mussa and Rosen (1978), there should be excess differentiation in the energy dimension.



(a) Markups vs Energy Efficiency



(b) Market Shares vs Energy Efficiency

FIGURE 5. Changes in Energy Efficiency, Markups and Market Shares by Firm

Notes: Each marker represents the location of a product in the energy efficiency dimension relative to markups (Panel a), or market shares (Panel b). Triangles represent the scenario without certification, and circles represent the scenario with certification. The products offered by each firm are represented by a different color. The figure shows that, without certification, brands E and F are the firms that reduce their markups the most (Panel a), but only Brand F tends to significantly gain market shares (Panel b).

Without ES, the larger differentiation of products in the energy efficiency dimension increases consumers' misperceptions of energy costs. On average, the increase in misperceptions is quite large: $276.6/consumer. This increase arises because without ES there is still a large share of uniformed consumers, and these consumers fail to account for the long term electricity costs of highly efficient models offered on the market.

In summary, removing the ES certification improves welfare because it leads to more differentiation in the energy efficiency dimension. Although the mass of models that just meet the minimum standard increases, the increase in efficiency for other models is large enough to improve the overall provision of energy efficiency, and consumers, in particular the ones with the highest income, benefit from this reallocation of products in the energy dimension. Pricing is also more (economically) efficient without certification. Markups decrease, especially for cheaper and low-efficiency models. Firms are almost as well-off without certification, although the effect on profits is heterogeneous.

Table 3. The Effects of Removing the ES Certification

	Income <\$50,000	Income ≥\$50,000 & <\$100,000	Income ≥\$100,000	All
Δ Sales weighted kWh/y				-35.7
				(3.4)
Δ Offered kWh/y				-33.2
				(3.2)
Δ Sales weighted price (\$)				12.8
				(1.8)
Δ Offered price (\$)				0.1
				(6.0)
Δ CV	33.4	21.9	40.9	30.3
	(2.7)	(2.9)	(4.5)	(3.3)
Δ CV, Informed (e=I)	29.1	23.9	38.4	29.3
	(2.3)	(2.4)	(4.0)	(2.8)
Δ CV, Uninformed (e=U)	21.0	8.0	2.1	10.0
	(2.8)	(2.8)	(5.1)	(3.3)
Δ Misperceptions	308.8	176.9	409.4	276.6
	(11.8)	(12.7)	(17.8)	(13.3)
Δ Misperceptions, Uninformed (e=U)	42.2	18.9	6.0	21.9
	(4.3)	(4.0)	(6.6)	(4.6)
Δ Externalities-Low	-13.4	-8.4	-9.2	-10.0
	(1.0)	(0.9)	(1.0)	(0.9)
Δ Externalities-High	-44.0	-27.7	-30.2	-33.0
	(3.2)	(3.0)	(3.2)	(3.1)
Δ Profits				4.3
				(0.8)
Δ Social Welfare-Low				44.6
				(4.5)
Δ Social Welfare-High				67.5
				(6.5)

Notes: The table reports the difference between a market without and with ES. The counterfactual basecase scenario is the market without ES. A negative sign implies that removing ES leads to a decrease in a particular metric relative to a market with ES. The model is bootstrapped 100 times. The mean and standard error (in parentheses) of the difference in various metrics are reported. All figures are in dollars per consumer. The negative externalities associated with electricity consumptions are evaluated for two scenarios: 'Low' refers to the lower range of the damage estimates, and 'High' refers to the higher range of the estimates. For both scenarios, the dollar value of the negative externalities decreases without certification, while the total welfare increases.

5.3. **Impact of Market Structure**

As discussed above and illustrated on Figure 5, the ES certification has a heterogeneous effect on firms, which is related to the degree of market power each firm holds. I now investigate this result in more details and illustrate how the market structure and the certification interact. I consider six different scenarios, where for each scenario I increase the amount of market power that a particular firm holds. To implement those scenarios, I simply increase the quality in the non-energy dimension for all products offered by a firm.[15]

The results are presented in Table 5 in Appendix C. Two patterns emerge. First, an increase in market power for a firm tends to increase the markups that this particular firm can extract when the certification is in effect. More generally, the simulations show that in more concentrated markets, it is easier for the dominant firm to price discriminate and take advantage of the fact that a fraction of consumers have a large willingness to pay for ES-certified models. This effect is intuitive, but it is, however, not guaranteed to happen. For instance, in the present context, a large increase in market power for Brand C does not translate in higher markups when ES is in effect. Why? It is because the price differentiation effect interacts with the segmentation effect that arises in oligopolistic markets subject to certification (Bonroy and Constantatos 2014). In the present case, the re-allocation of products in the energy efficiency space may lead to less (more) congested regions, which will impact firms' ability to charge higher (lower) markups. In the case of Brand C, in the absence of certification, its strategy is to reallocate about one third of its products at the lowest efficiency level. It then becomes one of the dominant firms in this region of the product space. When its market power increases, it can further exploit its dominant position for the market of low-efficiency models and maintain high markups, although products lose their certification.

The second important pattern is that the net effect on profits across firms is ambiguous and may move in the opposite direction of the change in markups. For brands A, B, D, and E, an increase in market power translates in higher markups together with higher profits when the certification is in effect. But, for brands B and F, this is not the case, markups and profits move in the opposite direction. For instance, when Brand F has a very dominant market position, it reduces markups when the certification is removed, but its profits increase. The fact that this firm can capture large market shares for low-efficiency models in the absence of certification explains this result.

[15]In my simulation model, quality in the non-energy dimension is captured by the product fixed effects recovered in the demand estimation. I can increase quality for a particular product by simply adding a fixed constant to the fixed effects, which is akin to producing a brand effect.

Altogether, these results show the complex relationship between market structure and coarse certification. In the absence of certification, the re-allocation of products at low-efficiency levels impacts the degree of competition in different regions of the characteristic space, which then leads to heterogeneous effects on markups and profits.

5.4. **Heterogeneity in Electricity Prices**

A distinctive feature of the U.S. electricity market is that electricity prices are subject to large variations across regions. For instance, during my sample period, the 5% percentile in average county electricity price is 0.08 $/kWh, while the 95% percentile is 0.18 $/kWh. This variation is attributable to various institutional features, such as the presence of regional environmental policies, liberalization of electricity markets by state regulators, and proximity to coal and natural gas reserves, to name a few (Zivin, Kotchen, and Mansur 2014). One implication of these heterogenous electricity prices is that the benefits of policies aimed at reducing energy demand can change widely across regions. Federal demand-side energy policies, however, are typically one-size-fit-all and do not account for such variation. This can lead to large losses in economic efficiency and highly heterogeneous distributional impacts.

In the context of the ES certification, variation in local electricity prices implies that the private net benefits of purchassing an ES-certified product would depend on the region where a household lives. In regions with low electricity prices, the reduction in lifetime energy costs associated with ES may be too low to compensate for higher retail prices; and vice-versa when electricity prices are high. Table 6 in Appendix C decomposes the change in consumer surplus in the main simulation (Table 3) for households living in regions of the U.S. with low (less than 0.11 $/kWh), medium (0.11 to 0.16 $/kWh), and high (more than 0.16 $/kWh) electricity prices. Across U.S. regions, the change in consumer surplus is positive for all households, and this holds across income groups. This means that households are still better off without ES, but especially in regions with high electricity prices. In these regions, the increase in the average energy efficiency offered, in the absence of ES, combined with high electricity prices bring large benefits: $81.8 per consumer.

Given the existence of a share of consumers that values energy costs in their purchase decision, it is when electricity prices are high that the ES is the less desirable. Another way to illustrate this is to show the equilibrium outcomes, with and without certification for different levels of electricity prices. In Appendix C (Table 7), I show that if all consumers were to pay a very low electricity price, 0.05 $/kWh, ES is welfare improving. With such low electricity prices, consumers' private benefits of adopting high-efficiency models are low. Therefore, firms do not have an incentive to offer such model. As a result, ES does not crowd out high-efficiency models and succeeds in increasing the average energy efficiency of the models offered on the market, which is desirable from a social standpoint.

5.5. **Impact of Consumer Sophistication**

Similarly to electricity prices, the share of informed/uninformed consumers is an important determinant of welfare. The crowding-out effect occurs when there is a large enough share of informed consumers. In markets where the share of uniformed consumers is large, the certification should then be the most beneficial. I show this in Appendix C (Table 8). I fix the latent shares of informed and uniformed consumers to various levels, and simulate the effect of removing the certification. When the share of uniformed consumers is 50% or more (scenarios 1-3), ES is welfare improving, and the gains in welfare associated with ES rapidly increase as the share of uninformed consumers comes close to one (Scenario 1).

The fact that the magnitude as well as the direction of the welfare effects depend on specific features of the market environment has important implications for the design of ES. The ES certification is rolled out on a technology-by-technology basis, and the EPA discontinues the certification of technologies if it considers that a market transformation has been achieved. My results suggest that consumers' abilities to account for energy costs should be a key determinant of whether a technology should be subject to ES or not. Using an elicitation procedure to measure energy literacy, (e.g., Blasch, Filippini, and Kumar 2017), could be a simple way to assess the share of informed/uniformed consumers in a specific market and then inform the design of ES.

5.6. **The Optimal Certification Requirement**

As shown above, the welfare effects of the ES certification depend on various features of the market environment. The regulator can also impact welfare by determining the stringency of the certification requirement. For instance, when crowding-out occurs, this implies that there is a relatively large share of consumers that would adopt high-efficiency models even in the absence of certification. In such market environment, the regulator could mitigate the crowding-out effect by setting a more stringent requirement, which will move the distribution of energy efficiency to better match the preferences of the informed consumers.

To illustrate, Figure 3 (Appendix C) compares the distribution of energy efficiency with and without the certification for different stringency requirements. For more stringent requirements, the two distributions tend to coincide and there is no crowding-out. Table 4 presents the welfare effects associated with these different requirements. The results suggest that a more stringent requirement, in the range of 40%, which corresponds to a doubling of the stringency that was in effect in 2011, would have made ES welfare improving. At this stringency level, consumers would have still been better-off without certification, but the change in consumer surplus is small. In fact, for all stringency levels, consumers are always better off without certification. For firms, this is the opposite. They tend to benefit from the certification, on average, irrespective of the stringency requirements. In sum, in imperfectly competitive markets, a coarse certification can benefit firms, but this comes at the expense of the consumers.

6. Conclusion

This paper develops a framework to study the welfare effects and incidence of coarse certification programs. The framework accounts for the strategic behavior of firms and the various behavioral mechanisms by which such certification can influence consumers. In particular, consumers trade off the coarse, but simple and salient signal provided by a certification, with more accurate, but difficult to collect and process information. I show that this trade-off can lead to an unintended consequence—a coarse certification may crowd out the provision of the hard-to-assess dimension of quality and induce excess bunching at the certification requirement.

I apply the framework to the ENERGY STAR (ES) program, one of the most important U.S. federal policies used to manage energy demand. Using the refrigerator market as a case study, I simulate the market with and without ES accounting for firms strategic behavior with respect to energy efficiency and price, and consumers' heterogeneity in the way they process energy-related information. In this context, I show that in the absence of the ES certification, products will be more differentiated in the energy efficiency dimension; where a large a share of products just meet the minimum energy efficiency standard, and another share has high efficiency levels that exceed the ES certification requirement that was in effect. Overall, the average energy consumption of the products offered on the market decreases without certification—ES thus crowds out the provision of energy efficiency. Consumers are better-off without certification, especially high-income households. Those are the households with the highest probability of being informed consumers that value

Table 4. The Effects of Removing the ES Certification for Different Stringency Requirements

	ES Certification Requirement (w.r.t Minimum Standard)										
	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
Δ CV	33.2	47.7	43.4	30.3	36.9	34.0	9.6	29.6	25.0	19.8	15.0
	(1.3)	(0.8)	(0.7)	(3.3)	(0.8)	(1.1)	(2.3)	(1.5)	(1.2)	(1.1)	(1.0)
Δ CV, Income <$50,000	38.2	55.2	52.1	33.4	40.6	36.6	12.9	29.3	25.3	21.4	16.8
	(1.2)	(1.1)	(0.9)	(2.7)	(0.8)	(1.1)	(1.8)	(1.5)	(1.3)	(1.2)	(1.1)
Δ CV, Income ≥$50,000 &	21.6	34.1	32.4	21.9	31.5	29.6	10.6	26.2	22.5	17.5	13.2
, <$100,000	(1.1)	(0.6)	(0.6)	(2.9)	(0.8)	(1.0)	(2.4)	(1.3)	(1.1)	(1.0)	(0.9)
Δ CV, Income ≥$100,000	47.4	62.7	52.6	40.9	42.1	38.7	4.6	35.7	28.9	21.8	16.3
	(2.0)	(1.2)	(1.2)	(4.5)	(1.1)	(1.7)	(2.9)	(1.9)	(1.5)	(1.3)	(1.0)
Δ Externalities-Low	-13.2	-15.5	-12.0	-10.0	-8.2	-6.8	6.5	-6.1	-4.9	-3.7	-2.8
	(0.4)	(0.4)	(0.4)	(0.9)	(0.2)	(0.3)	(0.8)	(0.4)	(0.3)	(0.2)	(0.2)
Δ Externalities-High	-43.4	-51.2	-39.5	-33.0	-27.2	-22.5	21.5	-20.0	-16.3	-12.1	-9.2
	(1.5)	(1.3)	(1.4)	(3.1)	(0.8)	(1.0)	(2.5)	(1.2)	(1.0)	(0.8)	(0.6)
Δ Profits	1.7	-7.7	-9.8	4.3	-10.6	-10.7	-7.8	-8.2	-6.9	-7.0	-5.7
	(0.1)	(0.3)	(0.6)	(0.8)	(0.4)	(0.4)	(1.3)	(0.4)	(0.5)	(0.6)	(0.6)
Δ Social Welfare-Low	48.1	55.6	45.6	44.6	34.5	30.1	-4.7	27.5	23.1	16.4	12.2
	(1.7)	(1.3)	(1.3)	(4.5)	(0.8)	(1.2)	(2.0)	(1.7)	(1.3)	(1.0)	(0.7)
Δ Social Welfare-High	78.4	91.2	73.0	67.5	53.4	45.7	-19.7	41.4	34.4	24.9	18.6
	(2.7)	(2.2)	(2.3)	(6.5)	(1.3)	(1.9)	(3.4)	(2.5)	(2.0)	(1.6)	(1.1)

Notes: The table reports the difference between a market without and with ES. The counterfactual basecase scenario is the market without ES. A negative sign implies that removing ES leads to a decrease in a particular metric relative to a market with ES. ES improves social welfare (SW) for a certification requirement of 40% (in red), a doubling of the stringency that was in effect in 2011 (20%). Consumers are never better off with ES for all stringency requirements. Firms tend to slightly benefit under ES and this holds for various requirements.

energy costs in their purchase decision. The impact of the certification on firms' profits is small and heterogeneous.

Whether or not ES improves welfare and its distributional impacts depend on various features of the market environment. I focus on the degree of market power firms hold, energy prices, and heterogeneity in consumer sophistication. But other factors, such the marginal cost of providing energy efficiency, which should be technology specific ought to play an important role. Crucially, the regulator can influence the magnitude and direction of the welfare effects by determining the stringency of the certification requirement. In my context, I found that a more stringent requirement for ES-refrigerators could have made the certification welfare-improving.

The policy 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, ES 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 ES label favors the adoption of certified products, and induces firms to offer more of these products. In equilibrium, this bunching at the ES requirement may not necessarily translate in improvement in energy efficiency levels, on average. Moreover, in highly concentrated markets, the fact that consumers value the ES certification can facilitate second-degree price discrimination, and markups on both certified and non-certified products can be larger when ES is in effect.

References

Akerlof, G. A. (1970): "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism," *The Quarterly Journal of Economics*, 84(3), 488–500.

Allcott, H. (2013): "The Welfare Wffects of Misperceived Product Costs: Data and Calibrations from the Automobile Market," *American Economic Journal: Economic Policy*, 5(3), 30–66.

Allcott, H., and R. L. Sweeney (2016): "The Role of Sales Agents in Information Disclosure: Evidence from a Field Experiment," *Management Science*, 63(1), 21–39.

Amacher, G. S., E. Koskela, and M. Ollikainen (2004): "Environmental Quality Competition and Eco-labeling," *Journal of Environmental Economics and Management*, 47(2), 284–306.

Amano, T. (2017): "Ratcheting, Competition, and the Diffusion of Technological Change: The Case of Televisions under an Energy Efficiency Program," Ph.D. thesis, Stanford University.

Ashenfelter, O. C., D. S. Hosken, and M. C. Weinberg (2013): "The Price Effects of a Large Merger of Manufacturers: A Case Study of Maytag-Whirlpool," *American Economic Journal: Economic Policy*, 5(1), 239–61.

Bagwell, K. (2007): "The Economic Analysis of Advertising," vol. 3 of *Handbook of Industrial Organization*, pp. 1701–1844. Elsevier.

Berto Villas-Boas, S. (2007): "Vertical Relationships Between Manufacturers and Retailers: Inference with Limited Data," *The Review of Economic Studies*, 74(2), 625–652.

Blasch, J., M. Filippini, and N. Kumar (2017): "Boundedly Rational Consumers, Energy and Investment Literacy, and the Display of Information on Household Appliances," *Resource and*

Energy Economics.

Boatwright, P., A. Kalra, and W. Zhang (2008): "Research Note—Should Consumers Use the Halo to Form Product Evaluations?," *Management Science*, 54, 217–223.

Bolton, P., and M. Dewatripont (2005): *Contract Theory*. MIT press.

Bonnet, C., and P. Dubois (2010): "Inference on Vertical Contracts Between Manufacturers and Retailers Allowing for Nonlinear Pricing and Resale Price Maintenance," *The RAND Journal of Economics*, 41(1), 139–164.

Bonroy, O., and C. Constantatos (2014): "On the Economics of Labels: How their Introduction Affects the Functioning of Markets and the Welfare of all Participants," *American Journal of Agricultural Economics*, 97(1), 239–259.

Dranove, D., and G. Z. Jin (2010): "Quality Disclosure and Certification: Theory and Practice," *Journal of Economic Literature*, 48(4), 935–963.

Dubois, P., R. Griffith, and M. OConnell (2017): "The Effects of Banning Advertising in Junk Food Markets," *The Review of Economic Studies*, 85(1), 396–436.

Eichholtz, P., N. Kok, and J. M. Quigley (2010): "Doing Well by Doing Good? Green Office Buildings," *American Economic Review*, 100(5), 2492–2509.

Fischer, C., and T. P. Lyon (2014): "Competing Environmental Labels," *Journal of Economics & Management Strategy*, 23(3), 692–716.

GAO (2011): "ENERGY STAR Providing Opportunities for Additional Review of EPA's Decisions Could Strengthen the Program," Report to congressional requesters, US Government Accountability Office, GAO-11-888.

Goel, A. M., and A. V. Thakor (2015): "Information Reliability and Welfare: A Theory of Coarse Credit Ratings," *Journal of Financial Economics*, 115(3), 541–557.

Greenstone, M., E. Kopits, and A. Wolverton (2011): "Estimating the Social Cost of Carbon for Use in U.S. Federal Rulemakings: A Summary and Interpretation," NBER Working Paper 16913, National Bureau of Economic Research.

Harbaugh, R., J. W. Maxwell, and B. Roussillon (2011): "Label Confusion: The Groucho Effect of Uncertain Standards," *Management Science*, 57(9), 1512–1527.

Heyes, A., and S. Martin (2016): "Social Labeling by Competing NGOs: A Model with Multiple Issues and Entry," *Management Science*, 63(6), 1800–1813.

Holland, S. P., J. E. Hughes, and C. R. Knittel (2009): "Greenhouse Gas Reductions under Low Carbon Fuel Standards?," *American Economic Journal: Economic Policy*, 1(1), 106–146.

Houde, S. (2017): "How Consumers Respond to Environmental Certification and the Value of Energy Information," *The RAND Journal of Economics*, Forthcoming.

Houde, S., and J. E. Aldy (2017a): "Consumers' Response to State Energy Efficient Appliance Rebate Programs," *American Economic Journal: Economic Policy*, 9(4), 227–255.

Houde, S., and J. E. Aldy (2017b): "The Efficiency Consequences of Heterogeneous Behavioral Responses to Energy Fiscal Policies," Working Paper 24103, National Bureau of Economic Research.

Ito, K., and J. M. Sallee (2017): "The Economics of Attribute-Based Regulation: Theory and Evidence from Fuel Economy Standards," *The Review of Economics and Statistics*, forthcoming.

Jacobsen, M. R. (2013): "Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity," *American Economic Journal: Economic Policy*, 5(2), 148–187.

Kahneman, D., P. P. Wakker, and R. Sarin (1997): "Back to Bentham? Explorations of Experienced Utility*," *The Quarterly Journal of Economics*, 112(2), 375–406.

Ketcham, J. D., N. V. Kuminoff, and C. A. Powers (2016): "Estimating the Heterogeneous Welfare Effects of Choice Architecture: An Application to the Medicare Prescription Drug Insurance Market," Working Paper 22732, National Bureau of Economic Research.

Klier, T., and J. Linn (2012): "New-Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy standard," *The RAND Journal of Economics*, 43(1), 186–213.

Knittel, C. R. (2011): "Automobiles on Steroids: Product Attribute Trade-offs and Technological Progress in the Automobile Sector," *American Economic Review*, 101(7), 3368–99.

Kotchen, M. J. (2006): "Green Markets and Private Provision of Public Goods," *Journal of Political Economy*, 114(4), 816–834.

Leggett, C. G. (2002): "Environmental Valuation with Imperfect Information the Case of the Random Utility Model," *Environmental and Resource Economics*, 23(3), 343–355.

Mason, C. (2011): "Eco-Labeling and Market Equilibria with Noisy Certification Tests," *Environmental and Resource Economics*, 48(4), 537–560.

Mullainathan, S., J. Schwartzstein, and A. Shleifer (2008): "Coarse thinking and persuasion," *The Quarterly Journal of Economics*, 123(2), 577–619.

Muller, N. Z., and R. Mendelsohn (2012): "Efficient Pollution Regulation: Getting the Prices Right: Corrigendum (Mortality Rate Update)," *American Economic Review*, 102(1).

Mussa, M., and S. Rosen (1978): "Monopoly and Product Quality," *Journal of Economic Theory*, 18(2), 301–317.

Newell, R. G., and J. Siikamäki (2014): "Nudging Energy Efficiency Behavior: The Role of Information Labels," *Journal of the Association of Environmental and Resource Economists*, 1(4), 555–598.

Reynaert, M., and J. M. Sallee (2016): "Corrective Policy and Goodhart's Law: The Case of Carbon Emissions from Automobiles," Working Paper 22911, National Bureau of Economic Research.

Sallee, J. M. (2014): "Rational Inattention and Energy Efficiency," *The Journal of Law and Economics*, 57(3), 781–820.

Sims, C. A. (2003): "Implications of Rational Inattention," *Journal of Monetary Economics*, 50(3), 665–690.

Small, K. A., and H. S. Rosen (1981): "Applied Welfare Economics with Discrete Choice Models," *Econometrica*, 49(1), 105–130.

Stahl, K., and R. Strausz (2017): "Certification and Market Transparency," *The Review of Economic Studies*, 84(4), 1842–1868.

Walls, M., T. Gerarden, K. Palmer, and X. F. Bak (2017): "Is Energy Efficiency Capitalized into Home Prices? Evidence from Three US Cities," *Journal of Environmental Economics and Management*, 82, 104–124.

Ward, D. O., C. D. Clark, K. L. Jensen, S. T. Yen, and C. S. Russell (2011): "Factors Influencing Willingness-To-Pay for the ENERGY STAR Label," *Energy Policy*, 39(3), 1450–1458.

Whitefoot, K. S., M. L. Fowlie, and S. J. Skerlos (2017): "Compliance by Design: Influence of Acceleration Trade-offs on CO2 Emissions and Costs of Fuel Economy and Greenhouse Gas Regulations," *Environmental Science & Technology*, 51(18), 10307–10315.

Zivin, J. S. G., M. J. Kotchen, and E. T. Mansur (2014): "Spatial and Temporal Heterogeneity of Marginal Emissions: Implications for Electric Cars and Other Electricity-Shifting Policies," *Journal of Economic Behavior & Organization*, 107, 248–268.

Appendix A. Theory: Proofs and Additional Results

Social Outcome. The social planner aims to maximize the consumer surplus experienced from the consumers. He will then set the level of a for each consumer type i such that the marginal valuation of a experienced by each consumer type equals the marginal cost: $\gamma_i = C'(a_i)$.

Monopolist Outcome. The monopolist has prior beliefs about θ_L and θ_H, but not the underlying experienced utility. She will then base her optimal strategy based on her beliefs of θ_L and θ_H.

Formally, the problem of the monopolist choosing the level of attribute a and price p becomes the standard monopolist screening problem of Mussa and Rosen (1978):

$$\max_{a_H,a_L,p_H,p_L} \pi \cdot (p_L - C(a_L)) + (1-\pi) \cdot (p_H - C(a_H))$$

s.t.

$$\text{IRH: } \delta + \theta_H a_H - p_H \geq 0$$

$$\text{IRL: } \delta + \theta_L a_L - p_L \geq 0$$

$$\text{ICH: } \theta_H a_H - p_H \geq \theta_H a_L - p_L$$

$$\text{ICL: } \theta_L a_L - p_L \geq \theta_L a_H - p_H$$

The following lemma and proof follow closely Bolton and Dewatripont (2005).

Lemma 1. *At an interior solution:*

- *ICL and IRH are non-binding; and*
- *ICH and IRL are binding.*

Proof. **Step I.** If $\theta_H > \theta_L$, ICH and ICL cannot be both binding in a separating equilibrium ($a_H \neq a_L$, $p_H \neq p_L$).
If ICH and ICL are both binding and $a_H \neq a_L$, this implies $\theta_H = \theta_L$, a contradiction.

Step II. ICi and IRi, $i = \{L, H\}$, cannot be both non-binding in equilibrium.
If both constraints ICi and IRi are non-binding, the firm can increase its profit by slightly increasing p_i, a contradiction.

Step III. ICL is non-binding.

If ICL is binding, ICL and IRL implies that IRH is non-binding:

$$0 \leq \delta + \theta_L a_L - p_L = \delta + \theta_L a_H - p_H \leq \delta + \theta_H a_H - p_H \tag{11}$$

IRH non-binding implies that ICH should bind (by Step II). ICL and ICH are then both binding in equilibrium, a contradiction (by Step I).

Step IV. IRH is non-binding

Step III implies that IRL is binding (by Step II). If IRL is binding, ICH and IRL implies that IRH is non-binding:

$$0 = \delta + \theta_L a_L - p_L < \delta + \theta_H a_L - p_L \leq \delta + \theta_H a_H - p_H \tag{12}$$

Step V. IRL and ICH is binding

Steps III and IV together with Step II, respectively imply that IRL and ICH are binding.

If $\theta_H > \theta_L$, the single crossing condition holds. This ensures that the incentive compatibility constraint of the low type (ICL) is non-binding at the optimum. Moreover, if ICL is not binding at the optimum, the individual rationality constraint of the low type (IRL) must be binding, otherwise the firm could increase profit by slightly increasing the price p_L. By a similar argument, the incentive compatibility constraint of the high type (ICH) must be binding at the optimal, i.e., the consumer with a high valuation of a may have an incentive to purchase the technology offered to the consumer with a low valuation of a. The firm must then distort the prices and attribute a to ensure that it is not optimal for the high type consumer to purchase the technology with $a = a_L$.

Using the fact that IRL and ICH are binding, we can solve for prices as a function of the attribute levels. The relaxed form of the monopolist's problem is given by

$$\max_{a_H, a_L} \pi \cdot (\delta + \theta_L a_L - C(a_L)) + (1 - \pi) \cdot (\delta + \theta_H (a_H - a_L) + \theta_L a_L - C(a_H))$$

The first order conditions yield:

$$\begin{aligned} \theta_H &= C'(a_H^*) \\ \frac{\theta_L - (1 - \pi)\theta_H}{\pi} &= C'(a_L^*), \end{aligned}$$

and the optimal prices are given by:

$$p_L^* = \delta + \theta_L a_L^*$$
$$p_H^* = \theta_H(a_H^* - a_L^*) + \delta + \theta_L a_L^*$$

Proposition 1. *Relative to the social optimum, the monopolist under-provides quality to the low and high types, and extract all the consumer surplus from the low type.*

Proof. As in the standard screening problem, quality is under-provided to the low type because the following inequality must hold at a separating equilibrium:

$$\theta_L > \frac{\theta_L - (1-\pi)\theta_H}{\pi}$$

Given that $\gamma_L > \theta_L$, and the cost is increasing in a, i.e., $C'(\cdot) > 0$, there is further distortion in the level of a_L provided by the monopolist.
For the high type, given that $\theta_H < \gamma_H$ and $C'(\cdot) > 0$, the value of a that solves $C'(a_H) = \gamma_H$ is always larger than the value of a that solves $C'(a_H) = \theta_H$. Quality is thus also under-provided to the high type.

Proposition 2. *Define π_P^*, the profits obtained under a pooling equilibrium where both products bunch at the certification a^C, and π_S^*, the profits obtained under a separating equilibrium, where $a_L^* \neq a_H^*$ and $p_L^* \neq p_H^*$. If $a_L^* < a^C$ and $\tau_L = \tau_H = \tau$, we have:*

$$\frac{\partial(\pi_P^* - \pi_S^*)}{\partial \tau} \geq 0 \tag{13}$$

Proof. Under a pooling equilibrium at a^C, the firm sets $p^* = p_L^* = \delta + \theta_L a^C + \tau$. The profits are given by $\pi_P^* = \delta + \theta_L a^C + \tau - C(a^C)$. Clearly, the derivative with respect to τ is 1.

Under a separating equilibrium, with $a_L^* < a^C$ and $a_H^* < a^C$, the profits are given by $\pi_S^* = q \cdot (\delta + \theta_L a_L - C(a_L^*)) + (1-q) \cdot (\delta + \theta_H(a_H - a_L) + \theta_L a_L - C(a_H^*))$. The derivative of π_S^* with respect to τ is 0. Therefore, $\frac{\partial(\pi_P^* - \pi_S^*)}{\partial \tau} = 1 \geq 0$.

Under a separating equilibrium, with $a_L^* < a^C$ and $a_H^* \geq a^C$, the profits are given by $\pi_S^* = q \cdot (\delta + \theta_L a_L - C(a_L^*)) + (1-q) \cdot (\delta + \theta_H(a_H - a_L) + \tau + \theta_L a_L - C(a_H^*))$. The derivative of π_S^* with respect to τ is $1-q$. Therefore, $\frac{\partial(\pi_P^* - \pi_S^*)}{\partial \tau} = 1 - (1-q) \geq 0$.

Under a separating equilibrium, with $a_L^* \geq a^C$ and $a_H^* \geq a^C$, the profits are given by $\pi_S^* = q \cdot (\delta + \theta_L a_L - C(a_L^*) + \tau) + (1-q) \cdot (\delta + \theta_H(a_H - a_L) + \tau + \theta_L a_L - C(a_H^*))$. The derivative of π_S^* with respect to τ is 1. Therefore, $\frac{\partial(\pi_P^* - \pi_S^*)}{\partial \tau} = 0$.

A.1. **Equilibrium Outcomes with a Coarse Certification**

A coarse certification impacts demand in two ways. First, it creates a discontinuous jump in the marginal valuation of a at the certification requirement, which I note a^C. Second, it lowers the marginal valuation of a for all other values such that θ_i becomes $\hat{\theta}_i$ with $\theta_i \geq \hat{\theta}_i$. These two effects impact the social and monopolist outcomes as follows.

Social Outcome I: $\tilde{\tau}$ is a bias. If the parameter $\tilde{\tau}$ is a bias, the perfect information outcome where the marginal valuation of a is set equal to the marginal cost, i.e., $\gamma_i = C'(a_i^*)$, determines the socially optimal level of a for $i = \{L, H\}$. It is never socially optimal to bunch at the certification requirement.

Social Outcome II: $\tilde{\tau}$ is preference. If the certification enacts preferences and brings a utility gain of size $\tilde{\tau}$, it can be socially optimal to bunch at the certification requirement.

Lemma 2. *If with certification a_i^* solves $\gamma_i = C'(a_i^*)$ and $a_i^* > a^C$, then the socially optimal level of a for type $i = \{L, H\}$ is: $a_i^{Social} = a_i^*$.*
If a_i^* is the solution of $\gamma_i = C'(a_i^*)$, $a^* \leq a^C$, and $\gamma_H a_i^* - C(a_i^*) \leq \gamma_i a^C + \tilde{\tau}_i - C(a^C)$, then it is optimal to set $a_i^{Social} = a^C$.

Proof. If $\gamma_i = C'(a_i^*)$ and $a_i^* > a^C$, given that the cost function is increasing and convex, social welfare is maximized irrespective of the value of $\tilde{\tau}_i$.
When $\gamma_i = C'(a^*)$ but $a_i^* \leq a^C$, it may be optimal to further increase a_i and to locate a_i at the certification requirement a^C to take advantage of the discrete increase in the willingness to pay: τ_i.

Monopolist Outcome. With a coarse certification, where the requirement is set at a^C, and $D_{j=\{L,H\}}$ takes the value 1 if $a_j \geq a^C$ and zero otherwise, the monopolist's problem becomes:

$$\max_{a_H, a_L, p_H, p_L} \pi \cdot (p_L - C(a_L)) + (1-\pi) \cdot (p_H - C(a_H)) \quad \text{s.t.}$$

$$\text{IRH: } \delta + \hat{\theta}^H a_H + \tau_H D_H - p_H \geq 0$$

$$\text{IRL: } \delta + \hat{\theta}^L a_L + \tau_L D_L - p_L \geq 0$$

$$\text{ICH: } \hat{\theta}^H a_H \tau_H D_H - p_H \geq \hat{\theta}^H a_L + \tau_H D_L - p_L$$

$$\text{ICL: } \theta^L a_L + \tau_L D_L - p_L \geq \hat{\theta}^L a_H + \tau_L D_H - p_H$$

The following algorithm can be used to solve the optimization problem.

(1) Solve the relaxed problem using the IR and IC constraints of the monopolist's problem in the presence of a certification. If $a_L^* \geq a^C$ and $a_H^* \geq a^C$, this the optimal solution.

(2) If the solution of the relaxed problem is such that: $a_L^* < a^C$ and $a_H^* < a^C$, compare the profits for the following additional two scenarios.
   - Alternative Scenario 1: Set $a_L^* = a^C$ and $a_H^* = a^C$
   - Alternative Scenario 2: Set $a_H^* = a^C$ and solve the relaxed problem for a_L only.

   Between the solution of the relaxed problem and the two alternative scenarios, select the solution with the highest profit.

Proposition 3. *A coarse certification increases the overall provision of quality of a if the following conditions hold:*

(1) *without certification:* $a_L^* < a^C$ *and* $a_H^* < a^C$

(2) *with certification:* $a_L^* \leq a^C$ *and* $a_H^* = a^C$ *or* $a_L^* = a^C$ *and* $a_H^* \geq a^C$.

Otherwise, the certification decreases the overall provision of quality of a.

Proof. When the certification does not induce the firm to locate a_L and a_H at the certification requirement, the certification decreases the level of a because $\theta_i \geq \hat{\theta}_i$. It is only when the certification induces products to improve their efficiency levels to meet the requirement that the overall provision might increase. This occurs when without certification: $a_L^* < a^C$ and $a_H^* < a^C$, and with certification $a_L^* \leq a^C$ and $a_H^* = a^C$ or $a_L^* = a^C$ and $a_H^* \geq a^C$.

Appendix B. Additional Summary Statistics

TABLE 1. Market Shares and Model Shares, U.S. 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-Westinghouse	4%	-	-	-
LG	-	-	3%	
Others	50%	36%	30%	27%

Sources: Appliance Magazine; data compiled by the Department of Energy (market share), and 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. Summary Statistics: Retailer's Sample Demand Estimation

	Mean	S.D.
Promotional Price ($)	1311.0	583.7
Manufactuers' Suggested Retail Price ($)	1561.1	703.6
% ES-certified Models	78.9	-
Manufactuers' Reported kWh/y	510.1	74.5
Manufactuers' Reported kWh/y: ES	502.5	68.7
Manufactuers' Reported kWh/y: Non-ES	538.4	88.4
Overall Volume (Cu. Ft.)	22.9	3.1
% More Efficient Minimum Standard	16.5	7.3
Model Share (%) by Door Design		
Top Freezer	25.5	-
Side-by-Side	36.3	-
Bottom-Freezer	38.2	-
Avg # of Refrigerator Models by Zip Code-Trimester	129	45
Total # of Refrigerator Models: Demand Estimation	672	-

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 period 2008-2011.

Table 3. Summary Statistics Representative Choice Sets: FTC versus Supply Estimation/Policy Simulation

	Observed FTC 2011		Constructed Retailer's Sample	
	Mean	S.D.	Mean	S.D.
Model Share (%) by Brand				
A	16.7		10.3	
B	19.2		22.1	
C	15.5		19.1	
D	8.5		10.3	
E	20.6		11.8	
F	19.5		26.5	
Model Share (%) by Door Design				
Top Freezer	32.5		22.1	
Side-by-Side	37.9		41.2	
Bottom-Freezer	29.7		36.8	
Overall Volume (Cu. Ft.)	22.0	3.4	23.6	2.8
Manufactuers' Reported kWh/y	507.5	91.5	514.0	74.2
% Certified ES	58.4		67.7	
% More Efficient Minimum Standard	17.2	7.0	18.3	7.4
# Models	1,828		68	

Notes: The FTC provides data for all refrigerator models offered on the market for the year 2011. The first two columns report the mean standard deviation for various attributes "observed" in the FTC data. The ES certification status of each model offered was added using data from the U.S. EPA. The "constructed" choice set consists of a random sample of refrigerator models draws from the set of models offered by the retailer and used in the demand estimation. All values reported are not sales-weighted. The constructed choice set is used for both the estimation of the unit retail costs and the policy simulations.

Emission Factors.

Table 4. 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		U.S.EPA, 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: U.S.EPA[b]
NOx	$380/t	$4,591/t	low: Muller and Mendelsohn (2012), high: DOE[c]

Notes: (a) Externality costs associated with $CH4$ and $N2O$ are assumed to be the same as 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).

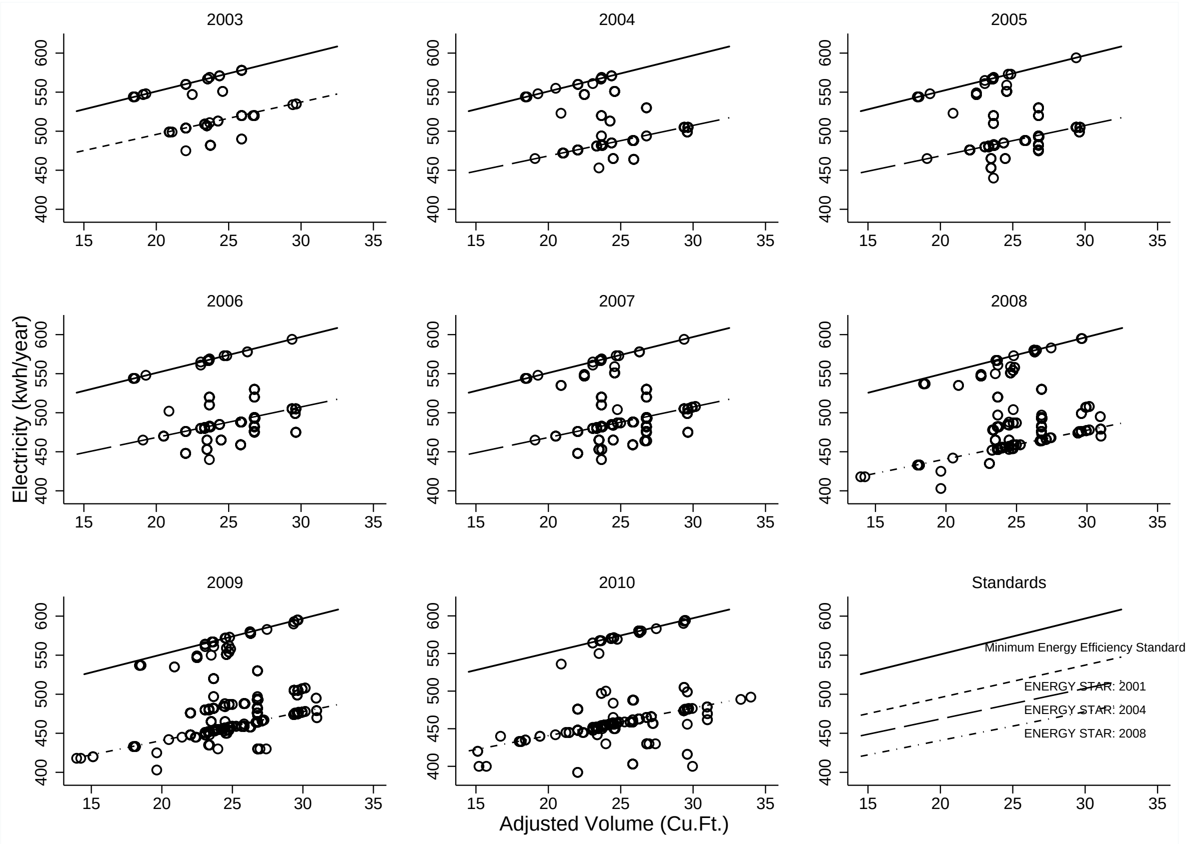


FIGURE 1. Evolution of Product Lines: Bottom-Freezer Refrigerators without Ice-Maker

Notes: Each dot represents a model offered in a particular year in the U.S. refrigerator market. The lines depict the minimum standard and ENERGY STAR requirement enacted in each year. Minimum standards are set as a function of refrigerator size and energy efficiency, and the ES requirement is defined relative to the minimum standards. The figure shows that refrigerator models bunch at the minimum and ES requirement and firms adapt quickly to new certification requirements to maintain this binary differentiation in the energy efficiency dimension.

Appendix C. Policy Analysis: Simulation Details and Additional Results

C.1. Simulation Details

To simulate the welfare effects of the ES certification, two market equilibria are simulated. In one scenario, the model is simulated with the ES certification. For the main policy simulation, the certification requirement is set relative to the federal minimum energy efficiency standard that was in effect in 2011. The minimum standard represents a constraint on firms' strategies with respect to the kWh/y offered for a particular model. Each refrigerator model in the choice set has a minimum standard that is defined with respect to the size of the refrigerator and door style. In this scenario, a model is certified if it meets or exceeds the certification requirement. That is, the certification process is assumed to be costless. In the second scenario, the model is simulated without the ES certification.

For each scenario, I solve for the Nash equilibrium where firms decide the price and kWh/y of each model they offer. I use the best-response iteration (Gauss-Siedl) algorithm, which consists of solving for the optimal combination of prices and kWh/y for one firm, holding other firms strategies fixed, and iterating over each firm until the strategies converge to a fixed point. I use the change in profits from one iteration to the other as the convergence criterion.

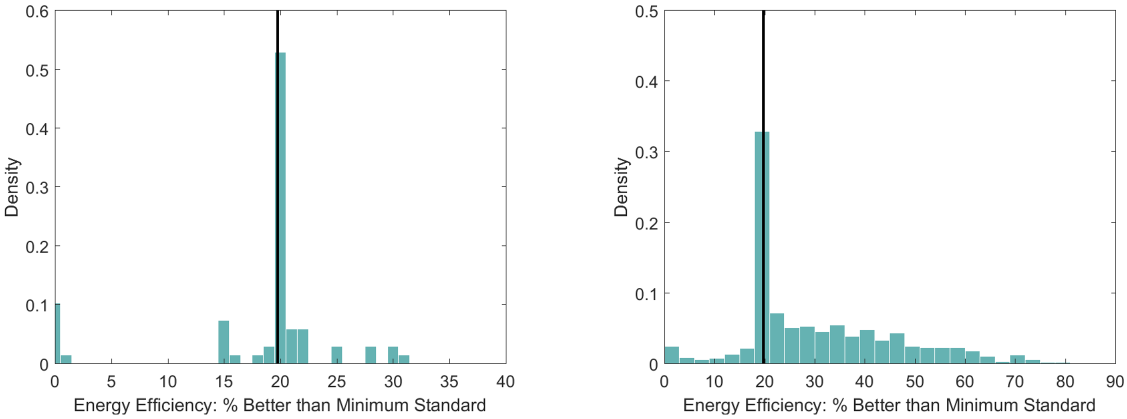
To account for uncertainty in the estimated parameters, I bootstrap the model. A bootstrap iteration consists of drawing the demand parameters and parameter of the marginal cost of providing energy efficiency from their estimated distributions and solving the model for the two scenarios. I then compare the equilibrium outcomes, and report the average and standard error of the differences for various outcomes, e.g., consumer surplus, profits, externalities, and social welfare, across the bootstrap iterations.

The demand model is simulated for a subsample of households that was used to carry the demand estimation. The size of the subsample has a notable impact on the computation time. I select a subsample of 3,500 households, which I found sufficient to obtain representative distributions of demographics and local electricity prices.

To simulate the demand model, I need to fix the quality in the non-energy dimension. The estimated product fixed effects play this role. Given that the demand model was estimated separately for the three income groups, there is a set of product fixed effects specific to each income group. Therefore, the perceived quality in the non-energy dimension differs across income groups.

The Nash equilibrium when ES is in effect may not exist due to the discontinuity created by the certification in the strategy space. For each bootstrap iteration, I set an upper bound (100) on the number of best-response iterations, and discard bootstrap iterations where this upper bound is binding. The best-response iteration algorithm usually converges with less than 10 iterations.

C.2. **Additional Results**



(a) Observed (2011), with ES

(b) Predicted, with ES

FIGURE 2. Observed versus Predicted Distribution of Energy Efficiency
Notes: Panel (a) is the distribution of products in the energy efficiency space observed for the representative choice set of 68 products. Panels (b) presenst the simulated distributions of products across all bootstrap iterations (approximately 100 iterations). In Panel (b), the model is simulated with the ES certification, where the requirement is set at 20% more stringent than the federal minimum energy efficiency standard.

Table 5. Profits and Markups by Brand:
with Sensitivity w.r.t. Market Power

	Brand A	Brand B	Brand C	Brand D	Brand E	Brand F
Basecase						
Δ Profits ($/consumer)	1.3	-0.4	0.7	-0.1	-0.6	3.5
Δ Markups ($/consumer)	2.0	4.5	-16.0	-12.5	-31.1	-27.3
Market Shares w ES (%)	16.7	10.9	17.7	6.6	17.1	31.0
Scenario 1: Brand A gains market power						
Δ Profits ($/consumer)	-3.4	-1.0	-0.2	-0.3	0.4	0.3
Δ Markups ($/consumer)	-11.3	-1.5	-20.4	-18.8	-76.8	-12.8
Market Shares w ES (%)	54.3	5.5	9.6	3.5	9.6	17.4
Scenario 2: Brand B gains market power						
Δ Profits ($/consumer)	-0.4	-9.6	-0.9	-0.5	-0.5	-2.1
Δ Markups ($/consumer)	-20.7	-20.6	-2.7	-1.9	-19.6	-18.3
Market Shares w ES (%)	9.2	47.6	10.7	4.1	10.6	17.9
Scenario 3: Brand C gains market power						
Δ Profits ($/consumer)	0.0	-0.5	-1.3	-0.2	0.0	-0.5
Δ Markups ($/consumer)	-3.7	1.7	-12.3	-11.0	-42.8	-3.9
Market Shares w ES (%)	6.6	4.5	62.5	2.8	9.1	14.5
Scenario 4: Brand D gains market power						
Δ Profits ($/consumer)	0.1	-1.2	-1.2	-6.3	-1.2	-2.6
Δ Markups ($/consumer)	-27.5	-8.3	-6.8	-12.9	-33.5	-20.4
Market Shares w ES (%)	11.0	7.4	11.9	36.2	12.4	21.2
Scenario 5: Brand E gains market power						
Δ Profits ($/consumer)	-1.3	-1.3	-2.9	-1.3	-8.8	-3.7
Δ Markups ($/consumer)	-29.1	-15.4	-13.9	-2.4	-36.8	-42.2
Market Shares w ES (%)	7.7	5.5	10.6	3.8	55.3	17.0
Scenario 6: Brand F gains market power						
Δ Profits ($/consumer)	-2.5	-2.1	-2.3	-1.0	-1.6	20.5
Δ Markups ($/consumer)	-22.7	-4.9	-39.7	-45.1	-62.1	-55.3
Market Shares w ES (%)	7.5	3.8	6.7	2.4	6.1	73.5

Notes: For each scenario, the difference in profits and markups is for a market without ES relative to a market with ES. A positive value indicates that removing the ES certification increases profits or markups. The 'Basecase' scenario corresponds to the main simulation. For all scenarios, the model was bootstrapped 100 times. Standard errors are not presented, but can be requested from the author. The difference between the values in red with the values of the corresponding column in the basecase scenario shows the effect of market power for the firm subject to the increase in market power.

Table 6. Change in Consumer Surplus Across U.S. Regions with Low, Medium, or High Electricity Prices

	<\$50,000	≥\$50,000 & <\$100,000	≥\$100,000	All
Δ CV	33.4	21.9	40.9	30.3
	(2.7)	(2.9)	(4.5)	(3.3)
Δ CV, Low Elec. Price: < 0.11 \$/kWh	15.5	11.0	22.5	15.4
	(1.3)	(1.5)	(2.3)	(1.6)
Δ CV, Medium Elec. Price: 0.11 to 0.16 \$/kWh	34.0	22.0	40.4	30.3
	(2.2)	(2.2)	(3.5)	(2.5)
Δ CV, High Elec. Price: > 0.16 \$/kWh	94.0	59.5	106.2	81.8
	(5.2)	(4.8)	(7.4)	(5.6)

Notes: The table reports the difference in consumer surplus between a market without and with ES. The first row is an average across all regions of the U.S.. The other rows present the change in consumer surplus for different regions of the U.S. based on average county electricity prices. Regions with high electricity prices benefit the most from removing the ES certification, because of the increase in high efficiency models offered in this scenario.

Table 7. The Effects of Removing the ES Certification as a Function of Electricity Prices

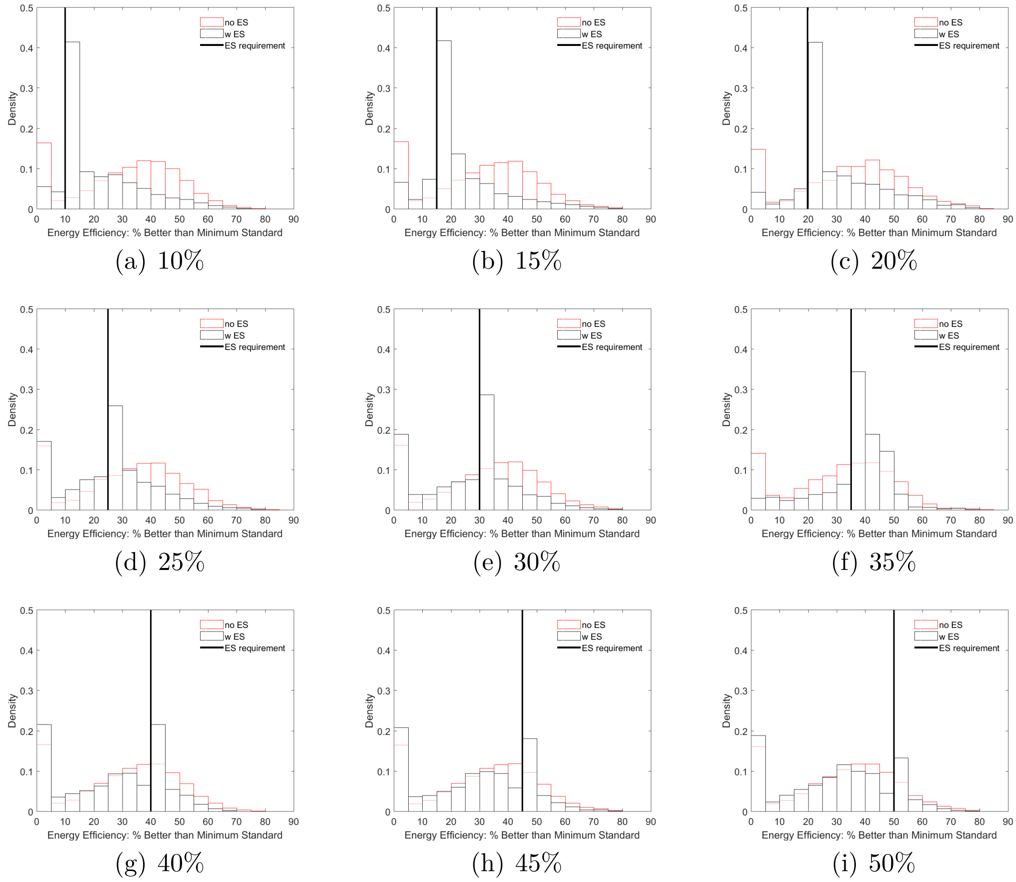
	Electricity Price (Faced by All Households)			
	0.05 $/kWh	0.10 $/kWh	0.15 $/kWh	0.20 $/kWh
Δ CV	14.5	11.1	24.0	163.5
	(1.8)	(1.3)	(3.3)	(27.8)
Δ CV, Income <$50,000	10.2	11.9	23.3	144.3
	(1.4)	(1.3)	(2.9)	(23.7)
Δ CV, Income ≥$50,000 & <$100,000	18.3	10.9	17.3	138.7
	(1.9)	(1.0)	(3.0)	(26.9)
Δ CV, Income ≥$100,000	12.8	10.8	35.9	224.8
	(2.3)	(1.8)	(4.2)	(35.1)
Δ Externalities-Low	21.5	2.4	-6.9	-24.2
	(0.9)	(1.0)	(0.6)	(2.6)
Δ Externalities-High	70.8	7.8	-22.8	-79.8
	(3.0)	(3.2)	(2.1)	(8.6)
Δ Profits	-3.3	-1.1	0.0	-22.8
	(0.4)	(0.4)	(0.7)	(6.5)
Δ Social Welfare-Low	-10.2	7.7	30.9	164.9
	(1.8)	(2.1)	(3.3)	(25.0)
Δ Social Welfare-High	-59.6	2.2	46.8	220.5
	(3.2)	(4.3)	(4.7)	(30.3)

Notes: The table reports the difference between a market without and with ES. The counterfactual scenario is the market without ES. A negative sign implies that removing ES leads to a decrease in a particular metric relative to a market with ES. Each column represents a scenario where the electricity price faced by all households is fixed to a specific value. ES improves welfare when the electricity price is the lowest: 0.05 $/kWh.

Table 8. The Effects of Removing the ES Certification as a Function of the Shares of Informed/Uniformed Consumers

	Scenarios: Share of Informed/Uniformed Consumers					Basecase
	I	II	III	IV	V	
Share of Informed, $H(e=I)$, with ES	0.09	0.21	0.31	0.42	0.67	0.35
Share of Uninformed, $H(e=U)$, with ES	0.67	0.58	0.51	0.42	0.24	0.38
Share of Informed, $H(e=I)$, no ES	0.12	0.27	0.38	0.50	0.73	0.55
Share of Uninformed, $H(e=U)$, no ES	0.88	0.73	0.62	0.50	0.27	0.45
Δ CV	-61.6	-35.7	-15.5	2.0	3.9	30.3
	(5.3)	(1.8)	(4.6)	(0.7)	(0.6)	(3.3)
Δ CV, Income <$50,000	-62.7	-32.0	-9.8	5.2	3.6	33.4
	(3.9)	(1.9)	(5.5)	(0.5)	(0.3)	(2.7)
Δ CV, Income ≥$50,000 & <$100,000	-45.4	-24.6	-8.0	5.0	3.2	21.9
	(5.1)	(1.6)	(3.4)	(0.7)	(0.4)	(2.9)
Δ CV, Income ≥$100,000	-87.4	-58.0	-34.1	-6.2	5.6	40.9
	(7.3)	(2.5)	(6.3)	(1.2)	(1.3)	(4.5)
Δ Externalities-Low	30.5	19.9	11.8	3.0	-2.3	-10.0
	(1.0)	(0.9)	(2.9)	(0.4)	(0.3)	(0.9)
Δ Externalities-High	100.5	65.4	39.0	9.9	-7.5	-33.0
	(3.2)	(2.9)	(9.4)	(1.5)	(0.9)	(3.1)
Δ Profits	-1.2	-0.9	0.9	0.4	0.2	4.3
	(0.6)	(0.5)	(1.0)	(0.3)	(0.3)	(0.8)
Δ Social Welfare-Low	-93.4	-56.5	-26.5	-0.6	6.4	44.6
	(6.0)	(2.5)	(7.0)	(0.9)	(0.7)	(4.5)
Δ Social Welfare-High	-163.3	-102.0	-53.6	-7.5	11.6	67.5
	(8.0)	(4.4)	(13.2)	(1.9)	(1.3)	(6.5)

Notes: The table reports the difference between a market without and with ES. The counterfactual scenario is the market without ES. In the different scenarios, the shares of informed and uninformed consumers was set to a constant. The probability $H(e=I)$ corresponds to the share of informed consumers with or without ES. The probability $H(e=U)$ is the share of uniformed consumers. When ES is in effect, the share of consumers that rely on ES can be computed by summing $H(e=I)$ and $H(e=U)$. The last column shows the results for the basecase scenario reported in the main text. Note that the share of informed and uniformed consumers vary across groups in the basecase scenario, but I only report the average across the three income groups. In the sensitivity scenarios, the share of informed/uniformed consumers are set equal across the all three income groups.



(a) 10% (b) 15% (c) 20%

(d) 25% (e) 30% (f) 35%

(g) 40% (h) 45% (i) 50%

FIGURE 3. Distribution of Energy Efficiency and Certification Stringency
Notes: Each panel plots the distributions of energy efficiency with (black) and without (red) the ES certification for a given stringency of the certification requirement. For stringency requirements ranging from 10% to 30%, the mass of the distribution without certification is more important at high efficiency levels.

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