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Bunching with the Stars: How Firms Respond to Environmental Certification

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Abstract. Voluntary environmental certification programs have been a popular tool used by governments, industry groups, and nonprofit organizations alike. A central question in the design of such programs is who should pay for them. In a context where firms respond strategically to a certification, the answer to this question is a priori ambiguous and, ultimately, empirical. This paper provides important insights on this question using ENERGY STAR, a voluntary certification program for energy-efficient products, as a case study. I show that firms are highly strategic with respect to this certification and extract consumer surplus associated with certified products via three mechanisms. They offer products that bunch at the certification requirement, differentiate certified products in the energy and nonenergy dimensions, and charge a price premium on certified products. I use these findings to motivate a structural econometric model with firms' strategic behaviors with respect to product line and pricing decisions and to investigate the incidence of a certification licensing fee to fund the certification program.

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1. Introduction

In recent years, consumer markets have been inundated with eco-labels and environmental certifications. These programs are sometimes managed by governmental entities or nonprofit organizations to nudge consumers toward more environment-friendly products. Other times, they are developed and offered by industry groups or trade organizations as part of corporate social responsibility initiatives. In either cases, a certification program that succeeds in raising environmental awareness among consumers can become an important determinant of market outcomes.

The costs of developing and managing an environmental certification program can be substantial. For programs that target consumer products, a certification must act like a brand and raise awareness, credibility, and recognition, which all require important and sustained marketing investments over time. In addition, there could also be large costs associated with monitoring and enforcing certification requirements. Therefore, a central question in the design of such a program is how it should be funded and who should ultimately pay for these costs.

In imperfectly competitive markets, the answer to this question is ambiguous. If firms believe that consumers value a certification highly, they will make product line and pricing decisions accordingly. When firms can exercise market power, an environmental certification then facilitates second-degree price discrimination. As a result, firms may benefit by extracting part of the consumer surplus associated with the high willingness to pay for certified products. If firms must also pay a certification licensing fee to fund the program, they could further raise the prices such that consumers bear most of the costs. These results are standard predictions of the theory of product differentiation, and have been discussed, implicitly or explicitly, in the theoretical literature on eco-labels and environmental certifications (Amacher et al. 2004, Harbaugh et al. 2011, Bonroy and Constantatos 2014, Fischer and Lyon 2014, Heyes and Martin 2016, Murali et al. 2019). Ultimately, in the presence of firms' strategic behavior, the incidence of a certification program will be determined by complex strategic interactions between firms and consumers. How should a particular program be funded is thus an empirical question.

The goal of this paper is to provide insights on this important question using the ENERGY STAR (ES), a voluntary certification program for energy-efficient products, as a case study. ES is one of the most well-known environmental certification programs not only in the United States but also globally. It is widely considered a success story, and the design of the program has been emulated in several countries.

To date, empirical studies on ES and more generally environmental certifications have focused on consumers' responses using in large part stated preferences data (Ward et al. 2011, Newell and Siikamäki 2014, Davis and Metcalf 2016) or have documented the diffusion of such certification (e.g., Kok et al. 2011). Unlike previous empirical studies, this paper takes a different angle.[1] I focus on showing firms' strategic response to the ES certification and the implication of such behavior in order to determine how such program should be funded.

My analysis proceeds in two steps. I first investigate firms' long-, medium-, and short-term strategic responses to the key features of the ES program. Using data from the U.S. refrigerator market, I show that manufacturers make long-term product line decisions to differentiate ES-certified models in both the energy and nonenergy dimensions. Although I do not precisely quantify the exact channels giving rise to these differentiation strategies, I provide evidence that the nature of the certification requirement, the underlying supply technology to deliver energy efficiency improvements, and demand characteristics all play a role. I also show that upstream and downstream firms, refrigerator manufacturers, and retailers, respectively, respond strategically through their pricing strategies. I investigate manufacturers' medium-term pricing responses together with retailers' short-term pricing strategies using three different natural experiments. All three strategies allow me to estimate the medium-run and short-run price premiums associated with ES-certified refrigerators ruling out various unobservables correlated with the certification. The analysis of the pricing strategies show how firms' market power contributes to the so-called green price premium. The estimates are highly consistent with each other, and also with previous market-wide estimates of consumers' willingness to pay (WTP) for the ES label (Houde 2018a). Across three income groups and different specifications, Houde (2018a) found that the WTP for the ES label ranges from \$16 to \$75. This corresponds to 1.2%–5.7% of the average price of a refrigerator. Focusing on the behavior of the manufacturers and retailers, I now find that ES-certified refrigerators command a price premium that ranges from 1% to 6%, which exactly matches the market-wide estimates of WTP. There is variation between the short-run premium determined by the retailers, which tends to be smaller and time varying, and the medium-run premium determined by manufacturers. I extend the analysis to other appliance categories (dishwashers, clothes washers, and air conditioners) and find price premiums of similar magnitude.

In the second part of the paper, I thus take firms' strategic behavior as given and study a key design feature of the ES program and more broadly environmental certifications: should such program be privately or publicly funded? Using a multiproduct oligopoly model with structural econometric estimates, I investigate the incidence of a certification licensing fee. The model endogenizes both product line and pricing decisions, as well as consumers' response to the certification.

The counterfactual exercise delivers key insights. First, I find that a licensing fee imposed on firms would be borne almost entirely by consumers and would have little impact on profits. Such a fee would increase the prices of certified products, which would then lower their adoption and lead to an increase in externality costs associated with energy consumption. Under various scenarios regarding the magnitude of the licensing fee, I show that the market and environmental impacts of such a fee could be minimal, while it could easily cover the cost associated with running the ES program. In sum, in a context of scarce public funds to run such program, I show that ES could be self-funded with little adverse environmental impacts, although the incidence would fall on consumers. Nonetheless, for all level of certification fees considered, I found that the introduction of such fee always leads to a small loss in social welfare. My results thus suggest that there is a rationale to use public funds to finance an environmental certification program.

The remainder of this paper is organized as follows. In the next section, I discuss the institutional features of the ES program. In Section 3, I investigate firms' product line decisions in response to ES for the U.S. refrigerator market. In Section 4, I focus on the pricing decisions for the same market. In Section 5, I extend the analysis to U.S. dishwasher, clothes washer, and air conditioner markets. In Section 6, I investigate the impact of costly certification, and conclusions follow in Section 7.

2. The ENERGY STAR Certification Program

The ES program is administered by the U.S. Environmental Protection Agency (EPA) and it covers more than 60 different product categories, ranging from large appliances, to consumer electronics, to residential and commercial buildings. The main feature of the program is the ES labeling scheme that firms can use in marketing their certified products. Since its establishment, however, the program has grown from a pure product certification scheme into one that also recognizes businesses' and organizations' efforts to promote and achieve energy efficiency. Over the years, the program has become an important part of the corporate social responsibility strategies of many businesses. Nonetheless, the core of the program remains the certification of specific technologies with the goal of achieving market transformation (Horowitz 2001).

Under the ES program, the product certification scheme works as follows. The EPA first targets technologies for which it considers energy efficiency improvements to be possible although they have not been adopted in their respective markets. It then establishes a technology-specific certification requirement. For several technologies, such as large appliances, the ES requirement is established relative to the existing federal minimum energy efficiency standard. In the United States, minimum standards consist of a mandatory upper level of energy consumption (and sometimes water) that each product offered on the market must meet, and they usually vary along key product attributes such as size and other dimensions of product design. These are attribute-based regulations (Ito and Sallee 2018), which allow manufacturers to meet energy efficiency requirements by making product design decisions along several dimensions. The ES requirement is usually defined as a simple percentage reduction relative to the corresponding minimum standard for a given technology and is thus also attribute-based.

The EPA usually announces a new requirement exactly one year in advance of the effective date. Once a requirement becomes more stringent, the EPA then requires that models that were certified under the previous requirement but do not meet the more stringent one be decertified.

Given the voluntary nature of the program and the EPA's desire to maximize participation among providers of energy-intensive technologies, the ES certification process has been designed to impose very little cost on program participants. For most of its history, manufacturers could certify their products by simply submitting a list of products that met the requirement to the EPA. Under this process, the certification has been essentially costless for manufacturers. This is especially true in the appliance sector, where manufacturers were required to test and measure the energy consumption of each model they offer to comply with the EnergyGuide mandatory labeling scheme and the federal minimum energy efficiency standards. Given that the ES certification uses the same information, no additional testing and measurement were required.

In 2010, however, the EPA changed its certification process. Following an investigation by the U.S. Government Accountability Office (GAO), which found that the program was too lenient in certifying technologies,[2] the EPA favored a third-party certification process with independent testing. Currently, the certification process is a hybrid process, whereby some technologies or manufacturers have to undergo third-party certification, whereas others can simply submit a list of products that meet the appropriate requirements. Manufacturers have opposed this new certification process on the basis that it imposed an undue burden on them. Since 2010, there has then been a recurrent debate on whether manufacturers or the government should pay to monitor and enforce the requirements. Recently, the Trump administration took this debate to another level by questioning altogether whether the federal government should allocate any funds to manage the whole ES program. Instead, the administration proposed to sustain the program and the ES brand with a licensing fee.[3]

Since its inception, the costs of developing and running the ES program has been substantial in large part because the EPA has used a marketing approach with the goal of creating a strong brand equity for the certification. Whereas from a marketing standpoint, the program is considered widely successful, from an economic standpoint, its effectiveness is ambiguous (Houde 2018a, b). The ES certification provides a coarse and salient signal to consumers about energy efficiency. In the United States, the certification aims to complement the mandatory energy label EnergyGuide, which provides product-specific estimates of energy operating costs for appliances and consumer electronics. In practice, the ES label and the EnergyGuide label act, however, as substitutes. The ES label does not provide additional information relative to the EnergyGuide label, but simpler one. As shown by Houde (2018a), in the appliance purchasing decision, consumers fall into three categories. A fraction of consumers, the most sophisticated, pay attention to EnergyGuide and local energy costs in their decision and ignore the ES label. Another fraction of consumers rely on the ES label to compare the energy efficiency of products in a binary manner and do not pay attention to EnergyGuide and local energy costs. These consumers have a large willingness to pay for the ES label that largely exceeds the expected energy savings of certified products. This suggests that behavioral phenomena such as warm glow (Habel et al. 2016) or the halo effect (Boatwright et al. 2008) might be at play. Finally, a large share of consumers do not pay attention to the energy dimension—they ignore both EnergyGuide and ES. The fraction of consumers for each of these categories varies with income, but this heterogeneity cannot be fully predicted by observables. Firms thus face an heterogeneous demand with latent types for ES products. As a result, they cannot perfectly discriminate to capture the high willingness to pay that some consumers have for certified products. But through strategic product line and pricing decisions, they can, however, screen consumers and extract consumer surplus in a way consistent with Mussa and Rosen (1978). I next show that firms' response to the ES program is consistent with such strategy.

3. Product Line Decisions

In the long-term, energy efficiency is one dimension of product line decisions that appliance manufacturers adjust in response to government regulations, consumer preferences, and new technologies. In this section, I thus investigate manufacturers' long-term strategic responses and show that the ES certification impacts product design decisions along several dimensions. Specifically, refrigerator manufacturers choose the energy efficiency levels of their products to exactly meet the ES certification requirement. Because of the nature of the certification requirement, which is akin to an attribute-based regulation (Ito and Sallee 2018), both supply characteristics and demand characteristics play a role in determining how manufacturers meet the ES certification and bundle energy efficiency with different dimensions of quality.

The data I use for this analysis come from multiple sources and focus on the U.S. full-size refrigerator market. I collected data from the Federal Trade Commission (FTC) to determine the refrigerator models offered on the market during the 2003–2011 period.[4] I matched the FTC data with data from the California Energy Commission (CEC) and from the EPA to recover additional attribute information and to determine the energy efficiency level of each model relative to the minimum federal standard. I use these three data sets to show the evolution of the choice set in the U.S. refrigerator market. I complement these data with transaction-level data from a large appliance retailer, which is active in most U.S. states and has significant market shares. These data cover a large number of refrigerator models offered during the 2008–2012 period. These data also contain additional attribute information that is not available in the FTC, CEC, or EPA data. A unique feature of the transaction data are that a large fraction of transactions (≈ 44%) were matched with household-specific demographic information. Houde (2018a) also used these data to estimate a demand model and to show how consumers respond to the ES certification. In this section, I use the detailed attribute information to show how ES-certified models differ along several dimensions of quality. I also provide additional stylized facts regarding the correlation of household characteristics and the adoption of ES models.

3.1. Bunching at ES

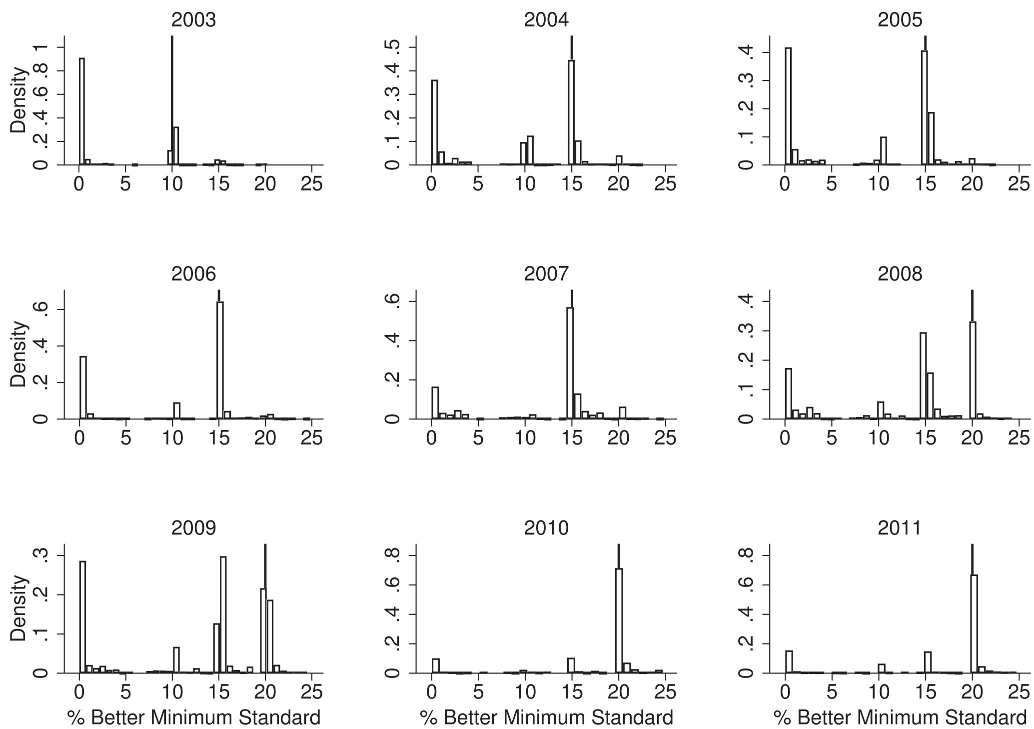
Figure 1 shows the empirical distribution of energy efficiency for full-size refrigerators from 2003 to 2010. I define energy efficiency as the percentage reduction between the electricity consumption manufacturers reported for each model they offered and the electricity consumption dictated by the federal minimum energy efficiency standard. Note that the minimum standard varies across models because it is set as a function of different attributes. In Figure 1, the ES requirement is identified by the thick vertical line. It was revised on January 2004 and on April 2008. Prior to 2004, the requirement was 10% more stringent than the minimum standard; between 2004 and 2008, the stringency was set at 15%; and after 2008 (until 2014), the stringency was 20%.

Figure 1 clearly shows that manufacturers differentiate their products with respect to energy efficiency. They tend to maintain a bimodal distribution where models either just meet the minimum standard or the ES requirement. The evolution of the distribution over time also shows that firms have the ability to adjust their product lines quickly. When the requirement is revised, which is usually announced exactly one year in advance, not only do they offer new models that meet the revised requirement the same year it is announced, but they also discontinue decertified models after the new requirement becomes effective. As time passes, the share of models that just meet the minimum standard tends to decrease, whereas the bunching at the ES requirement increases. This unraveling toward ES-certified models can be caused by two mechanisms. First, the ES certification might induce technological change facilitating the manufacturing of energy-efficient products. Second, competition effects might induce manufacturers to vertically differentiate by offering more energy-efficient models over time—a phenomenon similar to the one observed by Rysman et al. (2018) in the case of the LEED environmental certification for buildings.

Although the share of ES-certified models increases over time, manufacturers offer few highly energy-efficient models that exceed the ES requirement, unless a new requirement is announced. As discussed by Houde (2018), the coarse nature of the ES certification crowds out the offering of highly efficient models if the share of consumers that rely on the ES certification is large enough. It is also possible that manufacturers strategically retain innovation to influence the regulator and to ultimately induce a less stringent certification requirement (Amano 2017).

In the Online Appendix, I also present the distribution of energy efficiency offered by different manufacturers in the years 2006 and 2010 (Figure 1, Online Appendix A.1). The figure shows that firms favored a similar set of strategies, with each firm tending to offer both certified and noncertified

Figure 1. Energy Efficiency Offered: Full-Size Refrigerators 2003 to 2011



Source. Data from the Federal Trade Commission and EPA. Author's own calculations.
Notes. Each panel plots the empirical density of the energy efficiency levels offered (nonsales weighted) for full-size refrigerators. The *x* axis is the percentage decrease in electricity consumption (kWh/y) relative to the federal minimum energy efficiency standards. The ES certification requirement is identified by the thick vertical line. The requirement changed from 10% to 15% in 2004, and from 15% to 20% in 2008.

models. The bimodal distribution observed for the overall market (Figure 1) is, therefore, not caused by a segmentation of the market where different manufacturers occupy specific portions of the product space. The equilibrium outcome is more consistent with a scenario where all firms set different energy efficiency levels to screen heterogeneous consumers.

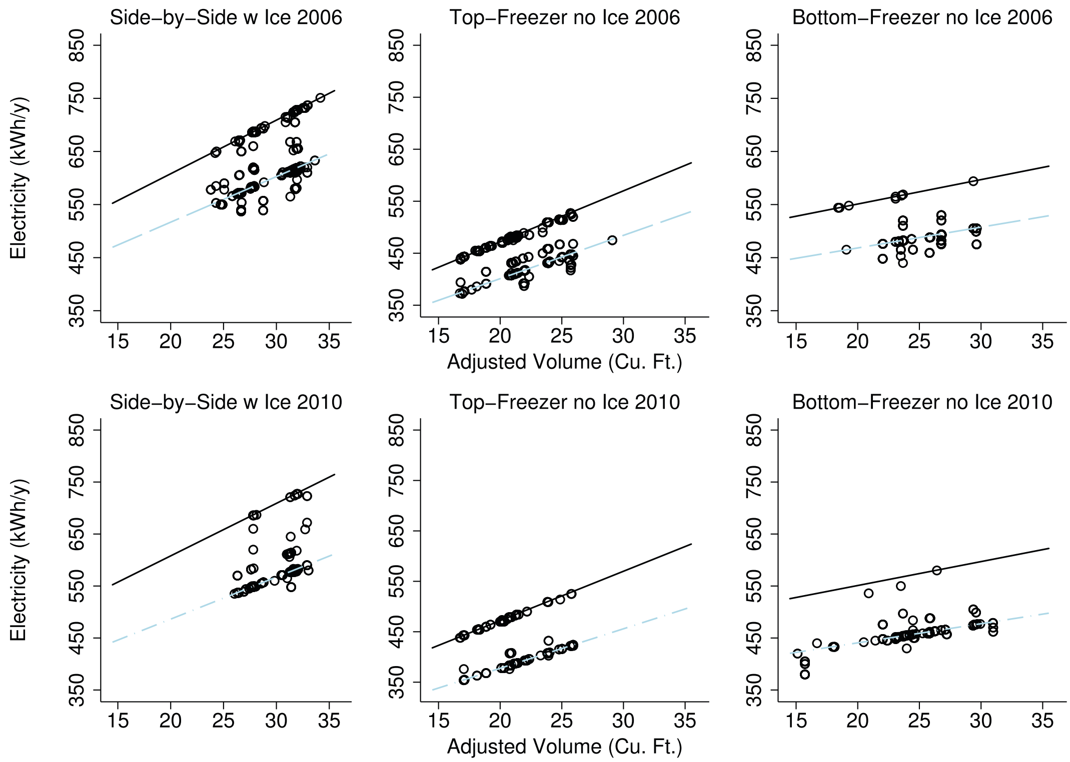
3.2. Differentiation in the Energy and Non-Energy Dimensions

The attribute-based nature of the ES requirement enables manufacturers to offer certified products by making design decisions along several dimensions. For full-size refrigerators, the overall volume,[5] the freezer location (top-freezer, bottom-freezer, or side-by-side), and the presence of an ice maker are the three main attributes used in the formula to define the ES requirement. Figure 2 illustrates how manufacturers exploit these dimensions to meet the energy efficiency requirements for the federal minimum standard and ES. Across different types of refrigerators, the joint distribution of volume and electricity consumption corresponds exactly to the requirements for the minimum standard and ES requirement established for each product class.

In addition to the nature of the certification requirement, supply and demand characteristics can induce a correlation between ES and specific attributes. Supply characteristics correspond to the manufacturing technology used to deliver energy efficiency gains. Demand characteristics are preferences that are correlated across different types of attributes. For instance, higher-income consumers with a high WTP for ES could also prefer larger refrigerators. To investigate the role of the attribute-based requirement, supply characteristics, and demand characteristics, Table 1 presents the correlation between ES and three categories of attributes: energy-related attributes used in the definition of the ES requirement, energy-related attributes not used for the requirement, and nonenergy-related attributes. This last category corresponds to refrigerator features that should increase quality, in a vertical manner, but should have little impact on energy use from an engineer standpoint. Examples of such features are the stainless steel finish of a refrigerator exterior and a door handle made of metal instead of plastic.

In Table 1, we observe a strong positive correlation between ES and attributes used to define the certification requirement, as expected. Whereas the direction of the correlation with other energy-related attributes tends to be positive, there are a few outliers. For instance, ES models that met the 2004 requirement were less likely to use LED lighting, which is not surprising

Figure 2. (Color online) Energy Efficiency vs. Volume: Full-Size Refrigerators 2006 and 2010



Source. Data from the Federal Trade Commission and EPA. Author's own calculations.
Notes. Each panel plots each model offered in the energy efficiency vs. volume dimensions. The *x* axis is the adjusted volume, which a weighted average of the refrigerator and freezer volumes measured in cubic feet. The *y* axis is electricity consumption measure in kWh/y and reported by the manufacturers. The federal mandatory minimum energy efficiency standard is identified by the dark line. The ES certification requirement is identified by the dotted line.

given that this technology was not as common prior to 2008. The two technology options of advanced cooling and advanced freezing, which mainly refer to the use of sensors to optimize the cooling and freezing processes, are, however, much more predominant among ES-certified models.

In sum, the positive correlation between ES and energy-related attributes is to be expected and suggests that the technology used to deliver energy efficiency gains can exploit several margins. Note that some energy-related attributes could also be correlated with consumer preferences, and the positive correlation found in Table 1 is a result of the combined effect of these various mechanisms. Focusing on the nonenergy-related attributes, however, allows us to better isolate the role of demand and vertical product differentiation. Interestingly, there is also a positive correlation between ES and attributes that improve quality but should have little effect on energy use. ES-certified models are more likely to have a stainless steel finish, a metal door handle, more baskets to store food, and a beverage rack. The only exception is the length of the warranty, which is shorter for ES-certified models, although the difference is economically small. Finally, the retailer data also contain a field indicating whether a particular model should have favorable in-store positioning, which is differentiated in four categories (good, better, best, and premium). ES-certified models are 5%–11% more likely to have a best or premium designation.

As further evidence that demand characteristics play a role in bundling of ES with energy and nonenergy attributes, Table A.1 (Online Appendix A.1) shows the correlation between ES and various demographic information available in the retailer's transaction data. Income level is positively correlated with the adoption of ES-certified models, which is consistent with manufacturers bundling vertical quality, and presumably more expensive features, with ES. For other demographics, the correlation is weak and not economically significant. Kok et al. (2011) also found that income is an important determinant and in fact, one of the main demographic variables explaining the adoption of ES-certified buildings.

4. Pricing Decisions

If some consumers value the ES label highly, firms should set prices above marginal costs and extract part of the willingness to pay associated with ES. The challenge in estimating the price premium associated with ES is that several attributes, in addition to energy

Table 1. Correlation Between ES and Product Attributes

	Non-ES	ES 2004 at 15%	ES 2008 at 20%	Non-ES vs. ES at 15%	Non-ES vs. ES at 20%
kWh/y	614.72	538.17	503.73	−76.54*	−110.99*
	(2,769)	(1,903)	(1,908)		
MSRP	1,539.65	1,792.52	1,719.10	252.88*	179.45*
	(2,750)	(1,894)	(1,894)		
Panel A: Energy-related attributes used for the ES requirement					
Adjusted volume	26.20	27.32	27.64	1.11*	1.44*
	(2,769)	(1,903)	(1,908)		
Freezer volume	6.57	7.61	7.73	1.04*	1.15*
	(604)	(868)	(1,394)		
Ice maker	0.40	0.61	0.71	0.21*	0.31*
	(2,769)	(1,903)	(1,908)		
Share side-by-side	0.44	0.48	0.43	0.04*	−0.01
	(2,769)	(1,903)	(1,908)		
Share bottom-freezer	0.20	0.26	0.37	0.06*	0.16*
	(2,769)	(1,903)	(1,908)		
Panel B: Energy-related attributes not used for the ES requirement					
Advanced cooling	0.11	0.28	0.41	0.18*	0.30*
	(2,769)	(1,903)	(1,908)		
Advanced freezing	0.06	0.22	0.20	0.16*	0.15*
	(2,769)	(1,903)	(1,908)		
LED lights	0.48	0.10	0.44	−0.39*	−0.04
	(193)	(166)	(337)		
Dual cooling	0.22	0.08	0.24	−0.13*	0.02
	(152)	(224)	(322)		
Panel C: Nonenergy-related attributes					
Stainless	0.09	0.16	0.25	0.07*	0.16*
	(2,769)	(1,903)	(1,908)		
Air filtration	0.04	0.04	0.15	0.01	0.11*
	(2,769)	(1,903)	(1,908)		
Advanced technology	0.09	0.24	0.36	0.15*	0.26*
	(2,769)	(1,903)	(1,908)		
# Baskets	1.68	1.88	1.98	0.19*	0.29*
	(174)	(209)	(399)		
Warranty (# years)	1.12	1.05	1.03	−0.08*	−0.09*
	(578)	(851)	(1,241)		
Beverage rack	0.37	0.60	0.40	0.23*	0.04
	(563)	(857)	(1,282)		
Metal door handle	0.15	0.21	0.30	0.06	0.15*
	(246)	(306)	(506)		
Best item positioning	0.53	0.63	0.59	0.11*	0.06*
	(1,080)	(732)	(782)		

Notes. The first column corresponds to refrigerators that never met the ES requirement. The second column corresponds to refrigerators that met the ES requirement effective between (2004) and (2008), which was set at 15% below the minimum federal energy efficiency standard. The third column corresponds to refrigerators that met the ES requirement effective after 2008 (April), which was set at 20% below the federal standard. The number of refrigerators in each cell varies because attribute information is missing for some models. The table shows that ES-certified models tend to differ from non-ES-certified along energy and nonenergy dimensions. In the fourth and fifth columns, the * denote statistical significance at the 5 percent level

use, are also correlated with the certification, as just shown above. Furthermore, manufacturers and retailers both make pricing decisions under different constraints. Manufacturers set the manufacturer suggested retail price (MSRP), which is a model-specific price that is adjusted during the shelf-life conditional on product line decisions. The MSRPs is thus a medium-term equilibrium response. Retailers offer promotional prices off the MSRPs. They can change the price of each model much more frequently, on a weekly and even daily basis, but are constrained by the level of the MSRPs. The retailers' price response thus captures the short-term equilibrium response.

I exploit three different natural experiments to estimate the medium- and short-term price premiums associated with the ES certification controlling for unobservables. I first use the revision in the certification requirement that occurred in 2008. Second, I focus on a decertification event that occurred in 2010, when a small number of refrigerator models lost their certification because manufacturers underestimated their energy consumption as a result of a problematic testing procedure. Finally, I consider an institutional feature of the refrigerator market and the fact that manufacturers sometimes offer identical refrigerator models that differ only with respect to their energy consumption. All three estimators show a small price premium for certified models that ranges from 1% to 6%, which is consistent with previous estimates of market-wide average consumers' WTP for the ES label in this market (Houde 2018a).

For this analysis, I rely on the transaction data from the large U.S. appliance retailer. The raw data consist of the transactions for each refrigerator model bought during the 2007–2012 period. I aggregate the data at the model and week levels. For each transaction, I observe three prices: the MSRP, the price actually paid by each consumer (net of sales tax), and the wholesale price paid by the retailer. This last price does not vary over time and effectively consists of the procurement cost to stock a particular refrigerator model that the retailer had to pay to the manufacturers. The MSRP is also set by the manufacturers but varies over time. The retailer takes the MSRP and offers discounts off this price. The price paid thus corresponds to a promotional price offered by the retailer and it varies widely over time. The MSRP and promotional price are usually clearly displayed in stores (physical and online). Note that the retailer has a national pricing policy and MSRPs are also set at the national. Therefore, the variation in both prices across stores is minimal.

Ultimately, consumers pay the price set by the retailer. For understanding firms' strategies in this market, it is, however, interesting to differentiate the effect of the ES certification on the MSRP and the final price paid at the retailer. Both prices capture an equilibrium response but at different levels in the vertical structure of the industry and by different types of firms. Moreover, the pricing strategies of manufacturers versus retailers are subject to different constraints, which can also induce interesting variation in equilibrium outcomes.[6] For instance, manufacturers usually set the same MSRP for all retailers in the national market and it is much more costly for them to change their prices frequently. The MSRP thus represents a medium-run price equilibrium and should predominately respond to important shocks. For retailers, it is much easier to vary the promotional price, although they are usually constrained by vertical contracts with manufacturers such that they cannot offer prices that are permanently below the MSRP. The promotional price thus better captures a short-run price equilibrium and is more likely to be subject to various idiosyncratic factors that a retailer will be subject to.

4.1. 2008 Decertification

In April 2008, the EPA increased the stringency of the ES requirement for full-size refrigerators, and this new requirement was announced exactly one year in advance. Following such revision, the policy of the EPA is that models that do not meet the more stringent requirement should have their ES labels removed or be clearly identified as not being compliant with the new ES requirement. Both manufacturers and retailers are responsible to relabel the products dependently of where the products are in the supply chain at the time a new requirement becomes effective. During the period spanning the effective date of the new requirement, it thus possible to observe the same refrigerator models with and without the ES label. Note that this change in labeling should impact only the information perceived by consumers and not the underlying attributes of the decertified refrigerator models.

I estimate the impact of the change in decertification using a difference-in-differences (DiD) estimator where I use refrigerator models that were never ES-certified or met the new certification as a counterfactual. The estimator is implemented with the following regression model:

$$log(P_{jt}) = \rho ESTAR_{jt} + \alpha_t + \gamma_j + \beta \mathbf{X}_{jt} + \epsilon_{jt} \qquad (1)$$

where α_t and γ_j are week-of-sample fixed effects and product fixed effects, respectively. The dependent variable is the log of the weekly price. The variable $ESTAR_{jt}$ is a dummy variable that takes the value of one if product j is certified in week t and zero otherwise. Therefore, the dummy variable $ESTAR_{jt}$ varies only if product j lost its certification in 2008, and the fixed effect γ_j captures all time-invariant product attributes specific to this refrigerator model. $\boldsymbol{X}_{jt}$ is a vector with additional controls. In one specification, I control for the number of months a product has been on the market, which is a proxy for product age. Controlling for product age allows me to capture dynamic pricing decisions correlated with shelf life. If decertified products tend to be systematically toward the end of their shelf lives, end-of-life sales could be confounded with the effect of decertification. I also consider predecertification linear time trends that vary for decertified models and other models. Finally, in another set of robustness tests, I consider rich fixed effects that capture brand-specific marketing strategies and contemporaneous shocks that would affect different classes of products that are close substitutes with decertified models. The coefficient ρ is then the quantity of interest and estimates the price impact of removing the ES label.

I estimate the effect of the 2008 decertification with data from January 2007 to December 2008. In 2008, the sample contains 2,752 different refrigerator models sold at the retailer, and 1,193 lost their ENERGY STAR certification in April 2008 (Table A.2; Online Appendix A.1). For all efficiency classes, I only include models that were on the market before and after the decertification event. I report results using both the MSRP and price paid at the retailer (also referred as the promotional price), which allows me to distinguish how manufacturers versus the retailer respond to the decertification.

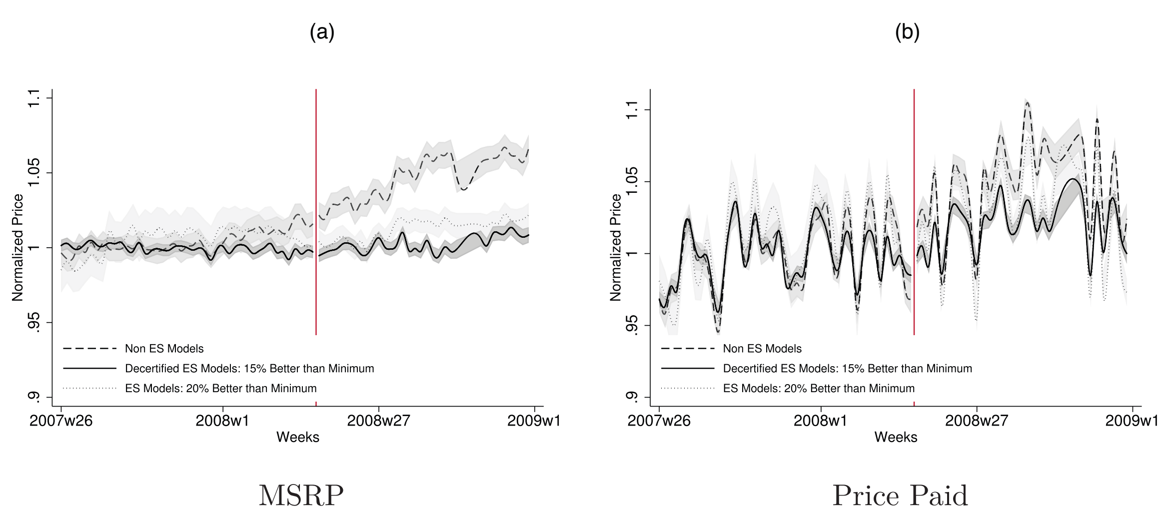
Before turning to the estimation, I provide graphical evidence of the impact of decertification on prices. On Figure 3, (a) and (b), the average normalized prices (MSRP and promotional) for three efficiency classes are shown: models that lost their certification, models that were not ES-certified as of January 1, 2007, and models that did not lose their certification following the revision in the requirement. Normalized prices are computed by dividing the price of each refrigerator model by its average price. Figure 3 plots the mean and the standard errors of a flexible regression spline fitted on the normalized price and allows for a discontinuity in the last week of April 2008.

For both the MSRP and the promotional price of decertified models, there is no graphical evidence of a discontinuous decrease in prices at the moment the new ES requirement became effective. Instead, we observe a relative change in prices, especially for the MSRP, that coincides with this date. The average prices of the non-ES models and the ES models that met the new certification requirement, which correspond to the two efficiency classes used as a control group, have a strong upward trend following April 2008. In relative terms, decertified models thus became less expensive in the postrevision period. The price patterns for promotional prices are similar, although they are also subject to large weekly cyclical variations. The validity of the DiD estimator relies on the parallel trend assumption in the prerevision period. Prior April 2008, we observe that the trends for all three categories of refrigerators tend to be similar. One exception is for the MSRP of non-ES models, which appears to be trending up as early as January 2008. In the estimation, I will thus consider a set of robustness tests where I exclude non-ES models.

Table 2 presents the first set of estimates. I first consider a simple regression model with only week-of-sample fixed effects and product fixed effects. The dummy $ESTAR_{jt}$ is then only identified off variation for ES models that met the certification prior April 2008 but not the more stringent requirement. The estimate of the ES price premium for the MSRP is 3.36% (column I) and for the promotional price is 1.71% (column II). They both suggest that the decertification led to a small but significant relative change in prices for decertified models.[7] In the next specification (specification II, Table 2), I also add controls for predecertification linear time trends specific to the three efficiency classes distinguished in Figure 3. With these additional controls, the DiD estimator provides estimates of the relative changes in prices off existing linear time trends. For both the MSRP and promotional prices, the estimates are larger: 5.87% and 2.89%, respectively.

Whereas the pre-existing linear time trends capture differences in pricing strategies across different efficiency classes leading to the decertification event, the linear assumption is restrictive. Next, I thus consider more

Figure 3. (Color online) Price Variation: 2008 Decertification Event



Notes. Each panel displays average normalized weekly prices, with 5% confidence intervals, of refrigerators that belong to different efficiency classes. The normalized price for each model is the weekly price (MSRP or transaction price) divided by its average weekly price. The average normalized price and standard errors in each efficiency class are computed by fitting a cubic spline on normalized prices. The vertical line identifies the decertification event.

Table 2. 2008 Decertification Event

	I		II		III		IV	
	MSRP	Paid	MSRP	Paid	MSRP	Paid	MSRP	Paid
Panel A: All efficiency classes								
ES = 1	0.0340***	0.0171***	0.0589***	0.0288***	0.0244***	0.0161***	0.0172***	0.00850*
	(0.00299)	(0.00312)	(0.00519)	(0.00542)	(0.00402)	(0.00412)	(0.00312)	(0.00367)
Observations	98,632	98,632	98,632	98,632	45,549	45,549	45,231	45,231
Panel B: Never ES-certified models excluded								
ES = 1	0.0172***	0.00657	0.0497***	0.0297***	0.0126***	0.00505	0.0110**	0.00300
	(0.00317)	(0.00357)	(0.00835)	(0.00849)	(0.00371)	(0.00417)	(0.00345)	(0.00443)
Observations	83,030	83,029	83,030	83,029	38,591	38,591	38,163	38,163
Model FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Week-sample FE	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Week-brand-price FE	No	No	No	No	No	No	Yes	Yes
Pre time trends	No	No	Yes	Yes	No	No	No	No
Produce age	No	No	No	No	Yes	Yes	Yes	Yes
Sample	Full	Full	Full	Full	Non Censored	Non Censored	Non Censored	Non Censored

Notes. Clustered (model level) standard errors in parentheses. The noncensored sample only includes models that entered the panel after January 2007, which allows me to construct a noncensored measure of product age. Panel A uses models for all three efficiency classes. Panel B excludes models that were never ES certified.

***, **, and * denote statistical significance at the 0.1, 1 and 5 percent levels.

flexible controls. One concern is that decertified models are toward the end of their shelf life, especially relative to the ES models that met the new requirement, and manufacturers and retailers price refrigerators differently based on the time a model has been offered on the market. In columns V and VI, I thus add flexible controls for product age. Specifically, I add dummies for month-of-age, which simply counts the number of months since a model's first sale is observed in the data, interacted with a dummy that identifies one of the three efficiency classes defined earlier. These controls capture dynamic pricing strategies as well as inventory management practices over a product life-cycle and differentiated by efficiency classes. As shown on Table 2 (specification III), these controls have little impact on the estimates. The fact that refrigerator models that got decertified were more likely to be toward the end of their life-cycle, relative to other efficiency classes, is therefore not an important source of bias.

An additional concern is that pricing strategies are correlated with product exit and entry, especially at the time of the decertification. As shown on Figure 2, firms are relatively quick to respond to a more stringent certification requirement by introducing new models. This results in a more crowded product space where decertified models have additional close substitutes, which could partly explain the decreases in prices postdecertification. To capture this possible confounder, I use a set of controls proposed by Ackerberg and Rysman (2005), which consists to use the number of products in different regions of the product space to control for substitution effects induced by product exit and entry. I implement such approach by first dividing the product space in terms of brand, size (quintiles), price point (quintiles), stainless steel option (zero-one dummy), and door design (three types). I then count the number of models offered each week in these groups and use this count (in log) as a control. I also add brand-by-week interacted with dummies for price quintiles to further flexibly capture product line and pricing strategies differentiated by regions of the product space. The estimates are presented in Table 2 (specification IV) and show that these controls have little effect on the results.

Across all specifications, the estimates suggest a small but robust *relative* decreases in prices for decertification models that range from 1.71% to 5.87% for MSRP, and 0.86% and 2.89% for promotional prices. At first, this pattern might appear surprising, such a relative price response is, however, consistent with the theory of product differentiation. Conceptually, the 2008s revision in the certification requirement consisted to increase the vertical distance between certified and noncertified models in one dimension of quality: energy efficiency. This in turn allowed relaxing price competition and thus enabled firms to increase markups on both ends of the energy efficiency spectrum, that is, never ES-certified models and the new ES models that met the requirement. The fact that we observe a stronger upward movement in the prices of low efficiency models is also consistent with the theory. As Mussa and Rosen (1978) first shown, when a firm uses vertical quality to screen consumers, higher markups should be set on low quality models. In sum, the pricing strategy observed in 2008 is thus consistent with a new medium/long-term equilibrium where firms could screen consumers more easily. Finally, note that firms eventually removed the models that did not meet the more stringent requirement. Firms might have thus decided to not change the price of these decertified models, because they knew that such models would eventually disappear from the market and not be part of the long-term equilibrium.

Whereas it is possible that firms decided to adjust to the new certification requirement by increasing the prices of refrigerator models that stayed on the market, alternative explanations are also possible. In 2008, the Great Recession was unfolding and demand for durables, such appliances, was rapidly falling. Manufacturers and retailers might have predicted that cash-constrained consumers would substitute toward cheaper and less efficient models, and decided to raise the prices on these models to compensate for the overall fall in demand. This could explain why the prices of non-ES models, which tend to be cheaper, started to trend upward as early of January 2008. In such case, the trend in prices of non-ES models would not be a valid counterfactual for decertified models. In Panel B of Table 2, I thus provide estimates where I exclude all models that were never ES certified from the control group. In these regressions, I am only comparing models that lost the ES label with models that met the more stringent certification requirement as soon as they entered the market. The estimates still suggest that the decertification led to a small but significant relative change in prices for decertified models. The estimates are, however, smaller. For MSRP, the estimates now range from 1.10% to 4.97%. For promotional prices, the magnitude of most estimates are reduced and now range from 0.3% to 2.97%. For MSRP, there are thus clear evidence that the ES label induces a price premium. But for promotional prices, the effect is not as pronounced.[8]

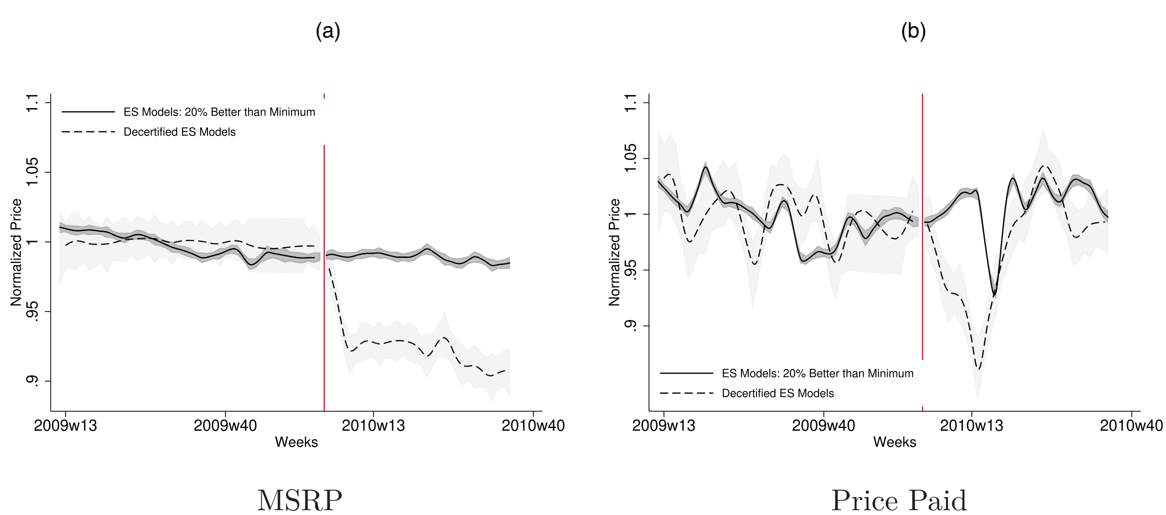
4.2. 2010 Decertification

In 2010, two appliance manufacturers misreported the actual energy usage of a small number of refrigerator models as a result of a problematic testing procedure. As discussed by Plambeck and Taylor (2019), one competitor, aware of this discrepancy, reported the inaccuracy to the EPA and the Department of Energy (DOE), which then proceeded to decertify 21 different refrigerator models. Unlike in 2008, this decertification announcement came as a surprise for affected manufacturers. This event thus provides a natural experiment where I can rule out inventory effects and changes in product lines. Moreover, it is highly likely that both manufacturers and retailers fully complied with the relabeling directive.[9]

Figure 4, (a) and (b) shows the average normalized MSRP and promotional prices for refrigerator models that lost their certification and for models that were ES-certified as of January 1, 2009. The figure clearly shows that firms responded by decreasing the prices of decertified models. We, however, observe a discrepancy in the pricing strategies of the manufacturers (MSRP) and the retailer (promotional prices). Whereas the drop in MSRP for decertified models is permanent, for promotional prices it reverted back to the average after about 12 weeks.

To estimate the effect on prices, I use a difference-in-differences estimator similar to that above with one exception: I restrict the sample to refrigerator models that met the 2008 ES certification only and estimate

Figure 4. (Color online) Price Variation: 2010 Decertification Event



Notes. Each panel is constructed as in Figure 3. In panels a and b, prices of the 16 models that were decertified are compared with the prices of ES models that did not lose their certification. The vertical line identifies the decertification event.

the decertification effect for the subset of models that lost their certification on January 20, 2010. I observe 16 models of the 21 models that lost their certification. Given that this decertification event attracted some media attention, I also consider a specification where I interact a dummy for the affected brands with a dummy for the postdecertification period. This control allows me to capture the (potential) negative brand effect that could be correlated with the decertification of a subset of models and use variation within brand to estimate the impact of the decertification.

Table 3 presents the results. The magnitude of the estimates is slightly larger than for the 2008 event and robust whether I control for predecertification linear time trends, brand effect, and month-of-age by efficiency classes fixed effects. For MSRPs, the ES premium ranges from 5.7% to 6.5%, and for promotional prices, it ranges from 1.4% to 4.1%. In Online Appendix A.2 (Table A.5), I also distinguish between the short-term effect (i.e., first 12/26 weeks after the decertification) and long-term effect (more than 12/26 weeks). The estimates are consistent with Figure 4 and suggest that the decrease in price for MSRP was permanent, but for promotional prices it was a large but short-lived effect. To compare, in Table A.6 (Online Appendix A.2) I also report the short and long-term effects for the 2008 decertification event. It shows that the 2008 decertification also led to a permanent decrease in MSRP. For promotional prices, I find some evidence of a more pronounced reduction in prices just six months after the decertification date (Panel A, specification II), which also mimics the patterns of the 2010 event.

Altogether, these two decertification events suggest that firms operating in the U.S. appliance market strategically set prices to account for the ES certification where the mere presence of the label impacts pricing. The 2010 decertification event provides clear evidence that both manufacturers and retailers responded to an unexpected labelling change, which was likely to be strongly enforced. Moreover, this event was, arguably, a local shock to the market, unlike the 2008 decertification event. The fact that only the prices of affected models changed in 2010 is thus also consistent with the theory of product differentiation. In this case, there were no change in vertical quality in the overall market, which lead the firms to adjust only the prices of decertified models.

One caveat with this natural experiment is that the reported energy consumption of the affected models were also revised and this change was reflected on the EnergyGuide label, which was also revised for the affected models. The price premium that I have estimated is then the combined effect of two information shocks: the loss of the ES certification and an increase in reported energy consumption. The next natural experiment distinguishes these two effects, and shows that the ES label tends to have a large effect on pricing.

4.3. Identical Pairs

One important institutional feature of the U.S. refrigerator market is the large number of products offered by manufacturers at any given moment in time. Although refrigerators are relatively simple technology, manufacturers offer a large number of variants with subtle differences. Above, I showed that the manufacturers rely on the ES certification to differentiate their products in the energy efficiency dimension, as well as in other dimensions that may not be energy-related. Although ES-certified models are systematically correlated with several attributes, in several cases, manufacturers offer product lines where two refrigerator models are identical along all observed dimensions except energy use. These identical pairs usually consist of models offered by the same brand, with the same size, freezer location, overall design, and technology features. However, they have subtle

Table 3. 2010 Decertification Event

	I		II		III		IV	
	MSRP	Paid	MSRP	Paid	MSRP	Paid	MSRP	Paid
ES = 1	0.0651***	0.0270***	0.0566***	0.0138	0.0636***	0.0407***	0.0642***	0.0261***
	(0.00587)	(0.00658)	(0.00654)	(0.00870)	(0.00594)	(0.00697)	(0.00580)	(0.00660)
Model FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Week-sample FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre time trends	No	No	Yes	Yes	No	No	No	No
Brand × post	No	No	No	No	Yes	Yes	No	No
Produce age	No	No	No	No	No	No	Yes	Yes
Sample	Full	Full	Full	Full	Full	Full	Non Censored	Non Censored
Observations	59,900	59,900	59,900	59,900	59,900	59,900	58,657	58,657

Notes. Clustered (model level) standard errors in parentheses. The noncensored sample refers to models that entered the panel after January 2009, which allows me to construct a noncensored measure of product age.

***, **, and * denote statistical significance at the 0.1, 1 and 5 percent levels.

differences in insulation, interior lighting technology, or sensors that allow them to achieve different levels of energy consumption. The existence of close to identical pair of products offers a unique opportunity to infer markups related to energy efficiency.

In my sample, I use the detailed attribute information to identify identical pairs. In particular, I first matched refrigerators by brand, freezer volume, refrigerator volume, height, width, freezer location, door material (stainless or not), ice-maker option, defrost technology, air filtration system, color, and door handle type. I then compare the online product description of the paired models to ensure that the products were both presented in a similar manner and appear to be identical from the consumer perspective.[10] Using this matching procedure, I found 50 identical pairs of refrigerator models that differ only with respect to their annual electricity consumption and their ES certification status.

For the present analysis, I sought to identify how variations in ES status and electricity usage within a pair impact the pricing strategy, and in particular markups. I use the wholesale price to compute the markup associated with each model. I then compare the markups for the models within each pair over the period 2008–2012. I use two measures of markup: the percentage markup of the MSRP and the percentage markup of the promotional price.

The regression model that I estimate is a simple fixed effects model where I regress the percentage markup on identical-pair fixed effects and week-of-sample fixed effects. I also consider an alternative specification where I control for year of entry, as two identical models may not have first entered the market at the same time. The year-of-market-entry fixed effects capture manufacturing cost shocks that may have impacted price (wholesale, MSRP, or transaction) at different points in time. I also consider brand dummies interacted with year-of-market-entry fixed effects to capture firm-specific temporal cost shocks. Finally, in these regressions, the quantities of interest are a dummy for the ES status and the manufacturers' reported electricity consumption of each model, which is measured in kWh/year. These two regressors vary within each pair. Moreover, they are not perfectly collinear because the difference in electricity consumption within an identical pair varies across pairs, and not all identical pairs have variation in ES status.[11] It is thus possible to disentangle the difference in markups due to the ES status versus the difference in electricity consumption.

Table 4 presents the results. The first take-away is that ES-certified models tend to have a higher markup, which is 0.9 to 2.64 percentage points higher, on average, depending on the specification. Note that with one exception, all estimates of the ES dummy are statistically significant across specifications. The second take-away is that for electricity consumption, the estimates are of the expected sign but statistically significant only for a few specifications. Moreover, the economic magnitude of the estimates suggests a much smaller effect—about half the effect of the ES label. For instance, the estimate of the first specification is 0.0849. Given that the average difference in electricity consumption within pairs is 80 kWh/year, this estimate corresponds to a 0.60% difference in markups. The third take-away is that the combined effect of the ES premium (0.9%–2.6%) and electricity consumption (0.3%–0.6%) suggests a difference in markups of 1%–3%, which is well above the discounted energy savings that consumers can expect from ES-certified models. To see this, a 80 kWh/year difference in energy consumption corresponds to a difference of about $100 in energy operating costs over the lifetime of a refrigerator[12] and the average retail price in the subsample of refrigerator models with an identical pair is

Table 4. Difference in Markups for Matching Pairs

	I		II		III		IV	
	MSRP	Paid	MSRP	Paid	MSRP	Paid	MSRP	Paid
ES = 1	0.0148**	0.0264***	0.0112*	0.0204***	0.00920	0.0170*	0.00909	0.0158*
	(0.00529)	(0.00602)	(0.00530)	(0.00600)	(0.00650)	(0.00737)	(0.00651)	(0.00738)
kWh/year	−0.0849*	−0.0537	−0.0980*	−0.0697	−0.0772	−0.0857	−0.0797	−0.0879
	(0.0432)	(0.0492)	(0.0428)	(0.0485)	(0.0449)	(0.0509)	(0.0449)	(0.0509)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Week-sample FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year-of-entry FE	No	No	No	No	Yes	Yes	No	No
Year-of-entry × Brand FE	No	No	No	No	No	No	Yes	Yes
	Pairs	Pairs	Pairs	Pairs	Pairs	Pairs		
Observations	6,845	6,845	6,845	6,845	6,845	6,845	6,845	6,845

Notes. The sample used for the estimations only includes weekly observations for identical pairs. The regressor kWh/year corresponds to a manufacturer's estimate of the annual electricity consumption for particular refrigerator model. Standard errors in parentheses.

***, **, and * denote statistical significance at the 0.1, 1 and 5 percent levels.

$1,000. Therefore, if electricity consumption were to be perfectly capitalized in the price, we should see a difference in markups of about 1%. Firms have thus the ability to leverage the simple and salient signal offered by the ES certification to extract higher markups beyond the pure financial gains associated with energy efficiency.

4.4. Discussion

Altogether, the three natural experiments show that firms operating in the appliance market are aware of the ES certification, believe that consumers value it, and consequently optimize their product lines and prices. Exploiting two decertification events and an institutional feature of the refrigerator market, I obtain three different sets of estimates of the price premium associated with the ES certification that are highly consistent with each other. The premium ranges from 1% to 6%, which also corresponds to the average, market-wide, WTP that consumers have for the ES label in this market (Houde 2018a).

By exercising market power, firms can thus extract part of the private benefits associated with the lower energy costs that ES-certified products deliver. In fact, most, if not all, of the private benefits associated with lower electricity consumption appears to be captured by firms through higher markups on certified models.

5. Additional Evidence: Other Markets

Given that the ES program covers more than 60 product categories, how do the results from the full-size refrigerator market translate to these other markets? Extrapolating the present results to a broader context should be done with caution. The market structure, underlying technologies, and certification requirements vary widely across markets targeted by the ES program, and so should the firms' responses. Thus, it is outside the scope of this paper to investigate firms' responses for all those markets.

In this section, however, I provide additional evidence for a subset of appliance categories that share similar characteristics in terms of market structure and purchase environment to the refrigerator market: dishwashers, clothes washers, and air conditioners. I also revisit the full-size refrigerator market, with a different data set to assess the external validity of the transaction data provided by the retailer. The data I use in this section consist of point-of-sales data provided by the NPD Group. These data are disaggregated at the model and month levels for the whole U.S. market.[13] Each observation consists of the monthly quantity of a particular appliance model sold in a large sample of appliance retail stores and the revenue associated with those sales. Using monthly quantities and revenues, I construct an unbalanced panel of monthly average prices at the model level. The panel covers the period 2005 to 2011 and spans several decertification events across appliance categories. Note that the data contain some attribute information, which allows me to identify models that meet more stringent certification requirements. However, detailed attribute information is not available, restricting my ability to conduct an analysis similar to the one carried out for the refrigerator market.

Overall, I find that the results are very consistent across appliance categories. Manufacturers offer products that tend to bunch at the ES certification requirement, and there is a small but noticeable price premium associated with the ES label.

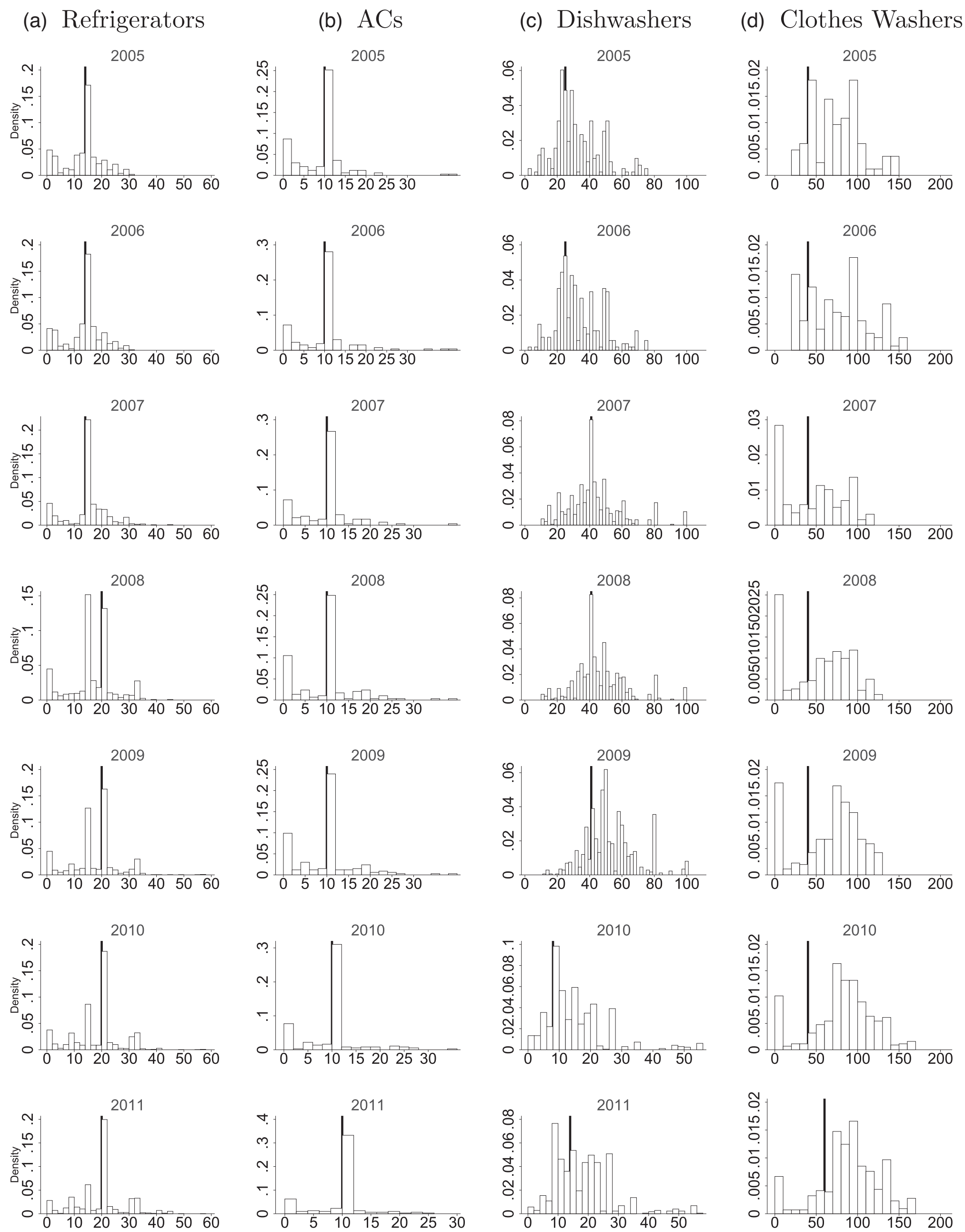
5.1. Product Lines: Energy Efficiency Offered

Figure 5 shows the empirical distribution of the energy efficiency offered (nonsales-weighted) for each appliance type. I consider that a particular model was offered on the market in a given year if I observe at least one sale. Under this assumption, the choice set in a given year reflects both manufacturing decisions and retail stores' inventories (i.e., models not offered by manufacturers in a given year but offered in retail stores).[14]

The distributions of energy efficiency for air conditioners follow a similar pattern to those refrigerators. Products bunch at the minimum standard, most products just meet the ES standard, and a few products exceed the certification requirement. There were no revisions in the requirement from 2005 to 2010, except in November 2005, when reverse cycle models, a particular type of air conditioner that can both heat and cool, were allowed to be covered by the ES program. As a result, a small number of models in the sample (n = 6, Table A.4, Online Appendix A.1) earned the ES certification at the end of 2005.

For dishwashers, products tend to bunch around the ES requirement, but the patterns are more idiosyncratic. This can be first explained by the fact that the minimum standard and ES requirement for dishwashers are defined by a combination of energy and water factors, which are inversely correlated. I conjecture that it is thus more difficult for manufacturers to make design decisions to achieve a precise level of energy efficiency. This appliance category was also subject to frequent revisions of the ES requirement. It was revised (effective date) in January 2007, August 2009, and July 2011. The minimum standard was revised in January 2010. The revised standard relied on a different approach to compute the energy factor, which explains the important difference in the distribution between 2010 and other years.[15] Prior to 2010, the fact that the minimum standard had been in place for a long time could explain why the minimum standard was not binding. The cumulative effect of small

Figure 5. Energy Efficiency Offered, 2005–2011



Source. Data from the NPD Group. Author's own calculations.
Notes. Each panel plots the empirical density of the energy efficiency levels offered (nonsales weighted) for four appliance types. The *x* axis is the percentage decrease in electricity consumption (kWh/y) relative to the federal minimum energy efficiency standards. The ES requirement is identified by the thick vertical line.

innovations throughout the years may have enabled manufacturers to increase efficiency beyond the minimum required.

For clothes washers, new ES requirements became effective in January 2007, July 2009, and January 2011. The revisions in 2007 and 2011 also coincided with changes in the minimum standard. Figure 5 shows that for all years, a large share of products just met the minimum standard, there was bunching at the ES standard in 2005 and 2006, but then models tended to exceed the ES requirement. In the most recent years, the distribution is bimodal, with a large share of products that just met the minimum and the remaining exceeding the ES standard. It should be noted that the minimum standard and ES requirement for this appliance category are also defined by a combination of energy and water factors. Similarly to dishwashers, the relative lack of bunching at the ES requirement compared with refrigerators and air conditioners could be explained by the fact that the technology required to meet the ES requirement is more complex, as it must optimize in the energy and water dimensions.

5.2. Pricing: Impact of ES Decertification/Certification

My empirical strategy to estimate the ES price premium across these various appliance categories is similar to the one I used before. I exploit the changes in the stringency of the certification requirement and the fact that a large number of models lost their ES labels over time. The estimator is implemented with the difference-in-differences estimator of Equation 1 for each appliance category separately. I report two specifications: a first specification with model fixed effects, month-of-sample fixed effects, and a control for product age (measured in months), and a second specification without a control for product age but with linear time trends that can vary in the predecertification period.

Table 5 reports the regression results. For all three appliance categories subject to at least one decertification event,[16] the decertification led to a decrease in price that is statistically significant (standard errors are clustered at the product level), and is 4.4%–5.0%, 8.2%, and 7.6%–8.7%, for refrigerators, clothes washers, and dishwashers, respectively. Controlling for predecertification linear time trends does not impact the results significantly, and I fail to reject that the pretime trends are the same for decertified and nondecertified models.[17] The effect of product age is negative and significant: as products stay longer on the market, the price tends to decrease. This is consistent with long-term inventory management. As newer models enter the market, manufacturers and retailers may want to liquidate decertified models to free up inventory. The fact that the prices of decertified models decrease even after controlling for product age means that the estimates are not simply capturing end-of-life sales. As I show next, even when the effect of inventories should be expected to have the opposite effect or can be completely ruled out, firms still set different prices for the exact same appliance models with and without the ES label.

In the market for air conditioners. the ES program was expanded in November 2005 to cover a particular type of model that was previously not eligible for certification. In my sample, I thus observe a small number of AC models that earned the ES certification. In 2005–2006, when firms were presumably stocking up on these models, inventories should have been increasing. Using the same strategy as before, I can then compare the prices of these models before and after the certification and use all other AC models as a counterfactual. I find that earning the certification leads to a price increase of 6.0%–7.3% (Table 5), which closely mirrors the effect of the decertification events. These estimates are, however, marginally significant, which is not surprising given that only six models in the sample earned the certification.

6. The Impact of a Certification Licensing Fee

One important but controversial feature of the ES program is that the certification process is designed to minimize the burden on manufacturers while maximizing their participation. From this standpoint, the program has largely succeeded. For technologies subject to the ES program, the certification is widely sought by businesses and organizations, which has

Table 5. Price Change After Decertification/Certification of ES Models, NPD Data

	Refrigerators		Clothes washers		Dishwashers		Air conditioners	
	(I)	(II)	(I)	(II)	(I)	(II)	(I)	(II)
Dependent variable: Log(price)								
Decertified	−0.044***	−0.050***	−0.082***	−0.082**	−0.076***	−0.087***		
	(0.016)	(0.017)	(0.031)	(0.035)	(0.013)	(0.015)		
Certified							0.060	0.073*
							(0.042)	(0.041)
Linear pre-trend	No	Yes	No	Yes	No	Yes	No	Yes
Months on market	Yes	No	Yes	No	Yes	No	Yes	No
Month-year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Product FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	77,922	77,922	20,507	20,507	36,381	36,381	11,248	11,248
R^2	0.954	0.954	0.897	0.897	0.934	0.935	0.835	0.835
No. of models	4,873	4,873	955	955	2,059	2,059	642	642
No. of certification changes	359	359	59	59	319	319	6	6

Note. Standard errors are clustered at the product level.
***, **, and * denote statistical significance at the 0.1, 1 and 5 percent levels.

resulted in consumers having a high degree of awareness and understanding toward ES (Murray and Mills 2011). Over the years, the program, and especially its certification process, has, however, faced a number of controversies challenging its reputation and trust among consumers. The GAO's 2010 covert testing investigation (GAO 2010) was a turning point that lead the EPA to revisit its certification process. There have also been repeated calls to privatize the ES program—a debate that became very salient recently with the Trump administration's proposal to eliminate public funding for the program. The rationale of the Trump administration is that because firms benefit from the program, a system where the certification is sustained by a licensing fee should succeed.

What would be the impacts of introducing a licensing fee to fund the program and who should pay for it? Ultimately, the incidence of such a fee would depend on the characteristics of each market subject to ES and it would impact both product line and pricing decisions. To provide an estimate of the impacts of licensing, it is thus necessary to account for how demand and supply characteristics interact in a strategic equilibrium where short-term pricing decisions and medium-term product line decisions are taken into account.

For this purpose, I use an econometric oligopoly model of the U.S. refrigerator market. The model uses a rich demand model for the decision to purchase a refrigerator, which was developed and estimated in Houde (2018a). The supply side model extends the oligopolistic model developed by Houde (2018b). Its main feature is that it endogenizes both prices and product line decisions with respect to the energy efficiency level of each product offered. This rich strategy space allows to capture the medium-term pricing responses[18] together with long-term product line responses to the ES certification.

Another key feature of the model is that it accounts for different dimensions of heterogeneity on both the demand side and the supply side. This rich representation of heterogeneity is key to capture firms' product differentiation strategies.

The oligopoly structure of the market is stylized and does not account for the full vertical structure of the industry. In particular, retailers and manufacturers are not distinguished. Instead, each firm in the model represents a strategic agent that corresponds to a manufacturer-retailer pair. Under this approach, the vertical contracts correspond to a scenario where each manufacturer-retailer pair acts cooperatively.[19] My proposed simplification of the vertical structure is necessary to have a tractable model. It is nonetheless very rich. It allows me to capture market power and endogenize the pass-through of a licensing fee for the ES program.[20] Under this assumption about the vertical contracts and the fact that the cost structure includes both the manufacturing and retail costs, the simulated pricing decisions capture the overall change in markups determined by the joint response of the manufacturers and the retailers.

In the Online Appendix, I describe the model in more details and discuss the data, estimation procedure, and simulation algorithm. For what follows, I provide a self-contained overview to guide the readers toward the simulations.

6.1. Econometric Oligopoly Model

The demand model consists of an information acquisition model where consumers (rationally) allocate attention to different pieces of energy information. It provides a framework to endogenize whether and how consumers pay attention to energy costs and the ES label. There are two dimensions of heterogeneity. The first is income—all the demand parameters vary across three income levels. The second is with respect to unobserved heterogeneity in consumer sophistication in the way they pay attention to energy information. The demand framework rationalizes this heterogeneity with a model of rational attention allocation wherein the purchasing decision consists of a two-step decision. In the first step, consumers decide whether to collect and process energy information. Based on their costs of collecting and processing such information, they can fall in three categories: consumers than do not pay any attention to energy-related information, consumers that solely rely on the Energy Star certification as a signal of energy-related information, and consumers that pay detailed attention to a measure of local energy costs. In the second step, consumers make a purchase decision given their updated beliefs regarding operating costs from the first stage.

The demand model, a function $D_j(p,f)$ that takes price and energy efficiency levels as inputs, is used as a primitive to a multiproduct oligopoly model where firms choose prices and energy efficiency levels of each product they offer. The model simulates a Nash equilibrium where prices and energy efficiency levels are determined strategically in an uncooperative game. On the supply-side, there are two primitives. The first is the cost of manufacturing model j by firm k, denoted $c^w_{kj}(f_{kj})$. This cost varies as a function of the energy efficiency level of the product. The marginal cost of providing energy efficiency is thus $\partial c^w_{kj}(f_{kj})/\partial f_{kj}$ and is a key parameter to estimate. I discuss it in more detail below. The second primitive is a model-specific unit retail cost, denoted c^r_j, which may capture advertising expenses, inventory costs, or warranty liabilities, but does not vary with the energy efficiency level of the product. In the simulations, the latter cost plays a lesser role with respect to the strategic response to a licensing fee.

The primitives of the model are all the preference parameters of the demand model, the manufacturing costs, and the unit retail costs. All these parameters are econometrically estimated using data from the retailer.

Table A.8 (Online Appendix A.3) presents the estimates of the demand parameters for all three income groups: 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. There are three important results. First, regarding heterogeneity with respect to income, as expected the price coefficients are inversely correlated with income, that is, the marginal utility of income decreases with income. The coefficient on electricity costs (θ), which captures the behavioral response to electricity costs for the share of perfectly informed consumers is smaller, in relative terms, for lower income households. Second, regarding the heterogeneity with respect to the degree of consumer sophistication, which is captured by the size of each of the three latent classes, the results show that lower income households are more likely to make product purchase choices without taking into account detailed energy use information (i.e., there is a high share of uninformed consumers in the lower income group). Third, note that the share of consumers that rely on Energy Star as a signal for energy consumption of the product ($e = ES$) varies from 20% to 10% across income groups. For these consumers, the effect of the Energy Star label is positive and suggests a high willingness to pay for certified products (between \$164 and \$430).

On the supply-side, the marginal cost of providing energy efficiency is the key parameter to estimate. It determines how firms will adjust to a ES certification requirement. I first estimate this parameter using the identical pairs of refrigerator models discussed in Section 4.3. For all paired refrigerator models, I estimate a simple hedonic regression where I exploit variation in the energy efficiency level within the pair group. I use wholesale price as a measure of the cost. I thus effectively assume that the wholesale prices correspond to the manufacturers' marginal unit costs and estimate the marginal cost by regressing the log of the wholesale price on a pair fixed effect, year-of-market-entry dummies interacted with brand dummies, and a proxy for energy efficiency:

$$ln(price^{wholesale}_{j,r}) = \alpha + \gamma_{j,j'} + Y_j \times Brand_j + \phi Efficiency_j + \epsilon_{j,r} \qquad (2)$$

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. I construct a proxy measure for energy efficiency by using a functional form such that energy efficiency is defined as the inverse of annual electricity consumption.

My goal is to not only to identify the parameter ϕ, but also whether and how it varies across firms. Given the modest sample size, I focus on distinguishing whether U.S.-based manufacturers versus non U.S.-based manufacturers have a different value of ϕ. To this end, I create a dummy that identifies the three main U.S.-based manufacturers/brands: Kenmore, GE, and Whirlpool, which I interact with ϕ.

For the identification of the marginal cost parameter, it is important that we also control for manufacturers' markups that could be present in wholesale prices. In the estimating equation, each pair fixed effect, $\gamma_{j,j}$, plays a crucial role in doing so—it captures the markup that is common to both products in a given pair. Given that we have a log-linear form, the pair fixed effects thus entirely capture markups that vary proportionally with the wholesale price, which is usually the case in an oligopoly setting[21] (Vives 1999).

The results are presented in Table A.9 (Online Appendix A.5). Across all manufacturers, the parameter ϕ has a value of 191.1. Once we allow for heterogeneity between U.S.- and non-U.S.-based manufacturers, we find that U.S.-based manufacturers have a lower value of ϕ relative to non-U.S.-based manufacturers, a difference that is statistically significant. The value of the parameter ϕ is 150 and 269, respectively, which means that U.S.-based manufacturers have a comparative advantage to producing incrementally more energy-efficient products.

To validate these findings, I also employ a second estimator to estimate the marginal cost parameter. One limitation of the pair matching estimator is the reliance on a small sample size. For the second estimator, I thus use the full sample of refrigerator models that I observe at the retailer and conduct an ordinary least squares (OLS) hedonic regressions using a large number of controls. These regressions are, of course, subject to a potential omitted variable bias due to the fact that we cannot guarantee that the observed attributes perfectly capture all variation in wholesale price across models. Table A.10 in Online Appendix A.5 presents these OLS results, and also suggest that U.S.-based manufacturers have a comparative cost advantage to produce energy-efficient products.

For the simulations, I thus calibrate the manufacturing cost function to capture the broad patterns found by the two estimators. I set the value of ϕ to 100 for U.S.-based firms, which approximately corresponds to the midvalue between the pair-matching and OLS estimators. For non-U.S.-based firms, with the exception of the Korean manufacturers, I will consider a high value for the marginal cost and set $\phi = 450$. Finally, for Koreans manufacturers, I set ϕ to the same value as the U.S.-based firms.

In addition to the manufacturing costs, firms are also facing retail unit costs associated with retailing large appliances, which may include advertising, transportation and inventory, and warranty. These costs are estimated using the first-order conditions of the pricing problem to recover the cost estimates (Houde 2018b). Note that given that the model captures the two main types of costs that arise in the vertical structure of the industry, that is, the manufacturing and retail costs, the model endogenizes the overall markup sets at the manufacturing and retailing levels, but does not distinguish between upstream and downstream markups.

The estimated model solves for a Nash equilibrium under different scenarios. In this context, the existence and uniqueness of a Nash equilibrium is not guaranteed because the ES certification introduces a discontinuity in the strategy space. I account for uncertainty due the potential multiplicity of equilibria by bootstrapping the model for a large number of perturbations in the parameter values. The simulation results that I report are the mean and standard errors across these bootstrap iterations.

Table 6. Impact of a Licensing Fee

	Licensing fee		
	\$10	\$25	\$50
Δ ES market share	−0.7%	−1.6%	−7.0%
	(0.3%)	(0.3%)	(0.3%)
Δ kWh/year	1.76	3.49	13.24
	(0.67)	(0.71)	(0.71)
ΔConsumer surplus (\$/unit)	−7.90	−19.68	−41.53
	(0.45)	(0.46)	(0.52)
Δ externality (low) (\$/unit)	0.49	0.98	3.71
	(0.19)	(0.20)	(0.20)
Δ externality (high) (\$/unit)	1.62	3.22	12.22
	(0.62)	(0.65)	(0.66)
ΔProfits (\$/unit)	−0.56	−0.57	0.70
	(0.17)	(0.19)	(0.17)
Δ Welfare (low) (\$/unit)	−1.40	−2.58	−9.73
	(0.60)	(0.63)	(0.66)
Δ Welfare (high) (\$/unit)	−2.53	−4.83	−18.25
	(1.00)	(1.04)	(1.08)
Fee collected (\$/unit)	7.55	18.65	34.80
	(0.02)	(0.05)	(0.07)

Notes. All results in dollars are averages per unit sold. The averages are taken across the bootstrap iterations. For the bootstrap procedure, each pair of scenarios is simulated 100 times with a small perturbation to the parameter values. The standard errors of the averages are reported in parentheses. The externality costs are computed for a lower-bound estimate of \$0.024/kWh and an upper-bound of \$0.079/kWh. The change in welfare is the sum of the consumer surplus, profits, externality costs (low or high estimate), and certification fee collected.

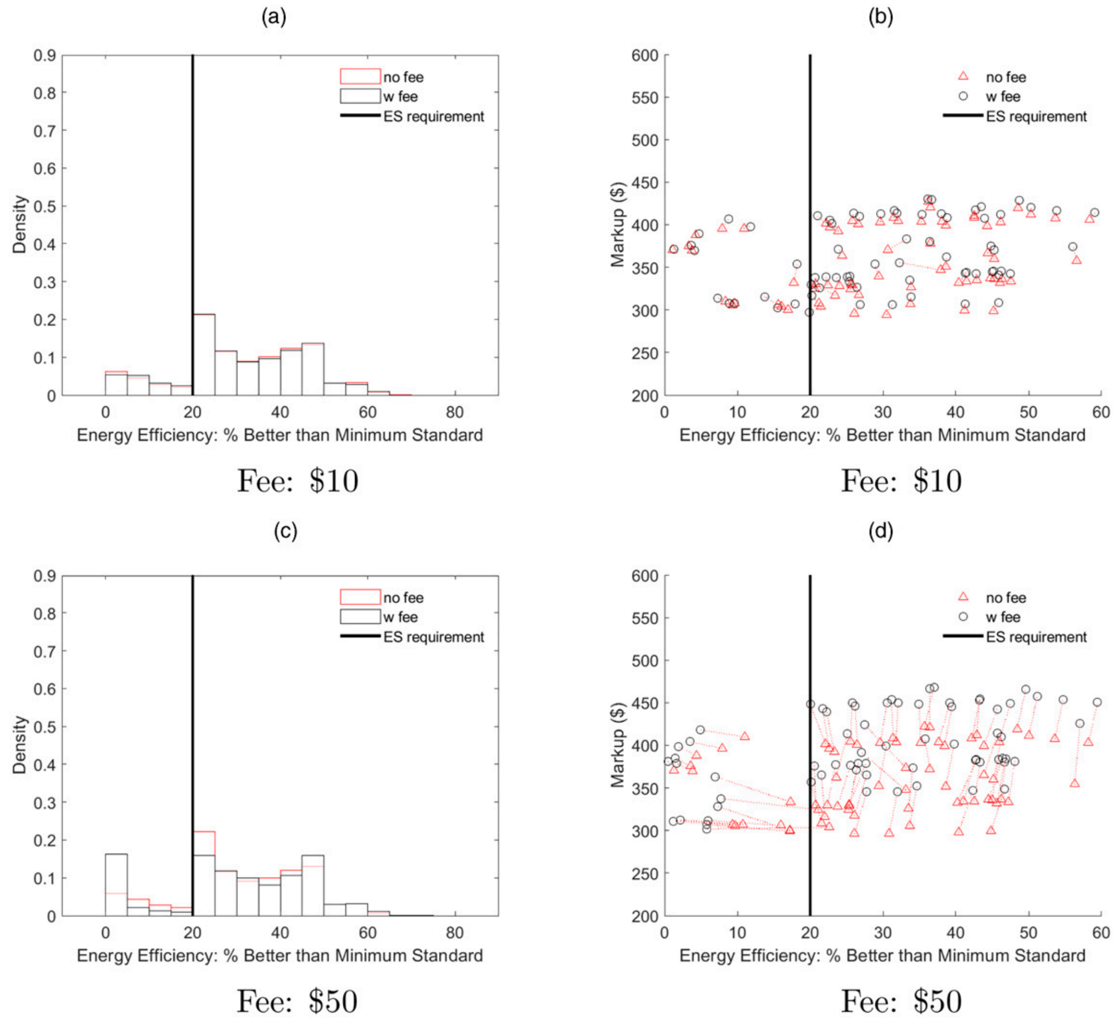
6.2. Simulations: Certification Licensing Fee

Table 6 presents the results for different licensing fees: \$10, \$25, and \$50. The first row shows the change in market share for ES-certified products. A fee of \$10 has little to no effect on market shares, but a fee of \$50 reduces market share by 7.0%. As shown on Figure 6, introducing a certification fee push firms to offer less products that bunch at the certification requirement. As the fee increases, we observe more product differentiation in the energy efficiency space. For instance, for a fee of \$50 the share of models that just meet the minimum standard (0% efficiency) and the share of highly efficient models both increase substantially. Overall, these changes in ES market shares translate into an overall increase in energy consumption. Specifically, for a fee of \$50, the average increase is 13.24 kWh/y for each refrigerator sold.

In Table 6, I translate these numbers into change in externality costs using various estimates of the marginal local and global damages associated with electricity generation in the United States, and emission factors (Table A.12, Online Appendix A.6). I also assume that a refrigerator lifetime is 18 years and sum and discount the externality costs over the lifetime, with a (social) discount rate of 5%. Focusing on the upper-bound estimate of the externality costs, the change in externality costs per unit sold is \$1.62 and \$12.22 for a fee of \$10 and \$50, respectively. Note that the overall size of the U.S. refrigerator market during that period was approximately 9 million units sold. Therefore, the certification fee increases the overall externality costs by in the range of \$10M to \$120M, depending on the scenarios. To put this number in perspective, according to the GAO (2011), the EPA and the DOE have spent \$57.4M/year, on average, during the period 2008–2011 to run the ES program. The amount collected from the certification fees for all scenarios is likely to cover these costs. For instance, for a certification fee of \$10, on average the amount collected is \$7.55 per unit sold and so about \$65M for the whole refrigerator market. This amount will be enough to fund the overall ES program and to compensate for the increase in externality costs.

The introduction of a licensing fee, however, comes at the expense of the consumers that bear most of the burden of the fee. The change in consumer surplus across different scenarios, show that, on average, a \$1 fee reduces the consumer surplus by about \$0.7. This reduction in consumer welfare is the combined effect of a change in price and energy-efficiency levels. In a multiproduct oligopolistic market, all products are affected by a fee in equilibrium. Figure 6 takes a close look at the equilibrium effect of a fee on markups relative to energy efficiency levels. For ES-certified models, there is a large increase in markups proportional to the magnitude of the fee. For models below the

Figure 6. (Color online) Impact of a Licensing Fee on Energy Efficiency and Markups



Notes. The panels on the left display the distribution of energy efficiency offered with and without a licensing fee. The panels on the right show the markups for each product offered and how these products move in the energy efficiency-markup dimensions. The line between each marker represents the movement between each equilibrium. Markups are computed using the simulated equilibrium prices minus the manufacturing and retail costs.

certification requirement, the change in markups depends on how energy efficiency is adjusted. Again, the scenario with a fee of $50 offers interesting insights. We see that markups increase for all products, whether they meet the ES requirement. By further differentiating their products in the energy efficiency dimension, firms can extract more of the consumer surplus.

The impact on firms' profits is economically small. Firms' ability to strategically adjust prices and product lines thus allow them to avoid the burden imposed by the introduction of the fee. For an overall welfare perspective, if we take into account the change in consumer surplus, profits, externality costs, and the increase in government revenues from the fee collected, licensing leads to a small welfare loss for all scenarios. In relative terms, the size of the loss ranges from about 10%–20% of the fee, and this loss is primarily due to a reduction in consumer surplus.

In Table 6, I also report the standard errors across the bootstrap iterations. The bootstrap procedure allows me to show that the potential multiplicity of Nash equilibria does not induce an overwhelming amount of uncertainty. Overall, the standard errors tend to be small relative to the averages.

7. Conclusions

In this paper, I first bridge the theory on environmental certification programs with three important empirical facts. Using the ES program as a case study, I show the different ways firms respond strategically to such program. In the U.S. appliance market, manufacturers make strategic product line decisions to exactly match the ES certification requirement. Second, I show that the certification enables firms to differentiate products in the energy and nonenergy dimensions. This differentiation is due to a combination of three factors: the attribute-based nature of the certification requirement, the underlying technology to provide energy efficiency improvements, and demand characteristics. The observed differentiation is consistent with second-degree price discrimination where ES-certified products are more expensive, more efficient, of higher (vertical) quality in other dimensions, and targeted toward higher-income households. Third, I show that ES-certified models have a systematic price premium, where this premium is attributable to higher markups and the effect of information alone. That is, ES models are more expensive not only because it is costly to design more energy-efficient technologies, they are also more expensive because a significant share of consumers have a high willingness to pay for the ES label, which enables firms to charge higher prices.

The fact that firms make strategic product line pricing decisions have important implications for the design and evaluation of the program. In the second part of the paper, I focus on investigating how should such program be funded. Using an econometric multiproduct oligopoly model, I show that setting a very modest certification licensing fee would be sufficient to fund the program and compensate for an increase in externality costs. Although such fee would have little impact on market and environmental outcomes, it would come at the expense of consumers and might not increase overall welfare. Therefore, my results show that there is a justification to use public funds to run a voluntary certification program such as Energy Star.

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Endnote

[1] Other studies have investigated different aspects of the supply-side response to environmental certification programs. Allcott and Sweeney (2016) investigate how sales agents promote the ES certification, but do not study product line and pricing decisions. They find that sales agents are more likely to selectively mention the certification to consumers prone to purchase ES-certified products. Another related example of an empirical study looking into firms' behavior is Rysman et al. (2018), which focuses on the Leadership in Environmental and Energy Design (LEED) program for buildings. The study shows that builders use the certification as a device to vertically differentiate new buildings from existing buildings in the same local markets. Spurlock (2013) also provides evidence that firms use second-degree price discrimination in the U.S. clothes washer market and focuses on the price impact of ES and minimum standards. Finally, Houde (2018b) estimates the overall welfare effect of the ES program taking into account firms' behavior.

[2] In its investigation, the GAO illustrated the leniency of the ES certification process by showing that it had certified a gas-powered alarm clock, one among other arguably nonenergy-efficient technologies (GAO 2010).

[3] This proposal from the Trump administration first came in March 2017 and was discussed by several media outlets, for example, https://www.eenews.net/stories/1060050976.

[4] The FTC data contain all refrigerator models that manufacturers offered in a given year in the U.S. market alone and are not sales-weighted. Every calendar year, appliance manufacturers are required to submit to the FTC a list of all models they are planning to stock in retail stores. This information is required by the FTC to comply with the EnergyGuide mandatory labeling program. The actual choice set faced by consumers might differ from what manufacturers are offering due to carry-over inventories. That is, a given refrigerator model can be offered by a manufacturer and can be stocked by retailers in a given year, but not in subsequent years, and still be present in retail stores during the entire period.

[5] A specific formula is used to compute the overall volume of a refrigerator in cubic feet. The volume of the freezing section is scaled by a constant greater than one, and it is added to the volume of the cooling section.

[6] For the present analysis, it is also particularly important to look at both the manufacturers' and the retailer's response because the policy exercise relies on a framework where both types of firms are modelled as a single strategic agent. For consistency with the model, I thus analyze and discuss those two types of prices.

[7] A positive coefficient for ρ means that prices are higher when products are certified; that is, $ES = 1$.

[8] Note that the discrepancies between the estimates for MSRP and promotional prices are consistent with the prior that the re-labeling of decertified models at retail stores was presumably imperfectly implemented given than it is much more difficult for the EPA to monitor retailers than monitoring whether manufacturers correctly labelled their decertified models before they got shipped. Given that the retailer had a national pricing policy, the retailer pricing decisions should then be interpreted as an equilibrium response for an expected level of compliance across all retail stores.

[9] One of the manufacturers sought court relief to postpone the decertification, but the U.S. District Court for the District of Columbia upheld the decision on January 18, 2010. On January 20, 2010, the EPA then published a press release announcing the decertification of these refrigerator models.

[10] I thank my research assistant Yuandong Qi for painstakingly verifying that the attribute information displayed in various online marketplaces was indeed identical for all the pairs identified by the matching procedure. The identical pairs used for this analysis have all been validated.

[11] For some pairs, both models meet the ES requirement, but have different reported electricity consumption estimates.

[12] If I assume an 18-year lifetime, 5% discount rate, and 0.11 \$/kWh electricity price. These three assumptions are in line with the values used by the DOE to perform cost-benefit analysis of the federal minimum energy efficiency standard program.

[13] The NPD Group collects data from several retail chains and claims that its data cover about 50% of the U.S. market in each appliance category.

[14] The FTC data, on the other hand, correspond exactly to what manufacturers aimed to offer in a given year. Even though there is a discrepancy between the two data sets, the distributions for full-

size refrigerators in Figure 5 look very similar to those earlier. The effects of inventories in the NPD data are thus likely to be minimal.

[15] The previous minimum standard, effective in 1994, relied on an energy factor that was a function of capacity and energy consumption. Since 2010, it is simply set as a function of total energy consumption (kWh/year).

[16] For air conditioners, there was no decertification event during the period 2005–2010.

[17] A predecertification linear time trend is specified for each decertification event for the 12 months preceding the revision. The appliance categories subject to three revisions have then 3×2 predecertification linear time trends estimated.

[18] The interpretation of the pricing decision is more in line with a medium-run equilibrium given that I do not model the short-run dynamic pricing strategy of the retailer. For this reason, the equilibrium prices in the model are closer to MSRPs.

[19] An alternative, but more complex scenario, would be to model an uncooperative game between manufacturers and retailers, which would bring double marginalization as in Berto Villas-Boas (2007).

[20] A priori, considering that manufacturers and retailers compete in a noncooperative manner should reduce firms' ability to maintain high markups and increase the pass-through of a license fee.

[21] For instance, in the classic setup of a Cournot game, markups are the inverse of the number of firms multiplied by the elasticity of demand.

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