The Implications of Market Structure for Appliance Energy Efficiency Regulation

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

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Draft: March 5, 2014

I derive and test predictions from the classic Mussa and Rosen (1978) second-degree price discrimination model using data from the United States clothes washer market. I find evidence consistent with price discrimination in the market response to energy efficiency policy changes. Concurrent with the effective dates of both the new 2004 and 2007 federal minimum efficiency and ENERGY STAR standards, within-model clothes washer prices dropped on average. The heterogeneous pattern of price reduction across market segments, and adjustments in the menu of products, were consistent with predictions from the price-discrimination model, and not with a perfectly competitive market.

JEL: D43, L51, Q48

Keywords: Price discrimination, minimum performance standards, energy efficiency

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The structure of the market for energy-consuming durables, such as appliances and automobiles, has important implications for energy efficiency regulation. These implications are explored in detail in this paper for the case of the United States (US) clothes washer market. Firms with market power that supply quality-differentiated goods have an incentive to under-supply quality - relative to the social optimum - to those with the lowest willingness-to-pay for a given quality characteristic in order to charge higher margins on products geared towards consumers with a higher valuation of that quality characteristic. This behavior is a form of second-degree price discrimination.

The classic model of a monopolist engaging in second-degree price discrimination in a quality-differentiated goods setting was articulated by Mussa and Rosen (1978). Many researchers have since extended this original model (e.g., De Meza and Ungern-Sternberg 1982; Katz 1984; Ronnen 1991; and Crampes and Hollander 1995). Most work to date addressing price discrimination in the context of efficiency regulation in particular has focused largely on the automobile market, and implications or repercussions of the corporate average fuel economy (CAFE) standard. Some examples include the work of Fischer (2005 and 2010), primarily focusing on a theoretical discussion of the comparative performance of various environmental regulation mechanisms in an industry with consumer preference heterogeneity for energy efficiency and firms with market power. In the area of household appliances, the question of market structure was empirically addressed by Ashenfelter, Hosken and Weinberg (2011). They demonstrated that the 2006 merger of Maytag and Whirlpool resulted in an increase in price and decrease in product variety for some appliances, an outcome consistent with consolidating market power. Additionally Houde (2012) demonstrated that the market response to the 2008 change to the ENERGY STAR (ES) standard for refrigerators was consistent with the Mussa and Rosen (1978) second-degree price discrimination model.

In this paper I extend the previous work in this area; I empirically demonstrate evidence consistent with price discrimination in the US clothes washer market by documenting the market response to tightening the US federal minimum efficiency (ME) standard. The theoretical prediction when a stricter ME standard is imposed in a market in which firms have been price discriminating with respect to energy efficiency is a drop in prices faced by consumers in the short run. Some evidence of an average drop in clothes washer prices was found by Chen, Dale and Roberts (2013) at the time of the January 1st, 2007 restriction to the US federal ME standard. In this paper I confirm this result for the 2007 standard change, as well as demonstrate that the average drop in prices was even more pronounced at the time of the January 1st, 2004 restriction to the federal ME standard. Additionally, I demonstrate that concurrent with the effective dates of both the 2004 and 2007 standard changes, the heterogeneous pattern of the drop in prices across various efficiency-related market segments, as well as patterns of change in the menu of products offered, are consistent with those predicted by the second-degree price discrimination model, and not readily consistent with a perfectly competitive market.

In particular, I use a model based off of the Mussa and Rosen (1978) articulation of monopolistic second-degree price discrimination. I discuss the implication of both a combined change in the ES and ME standards, and the oligopolistic structure of the market, in the context of this model and its extensions in the literature. I derive testable predictions regarding the price and menu adjustment response to a combined change in the ME and ES standards. The predictions differentiate between the case of a market in which firms can price discriminate versus a perfectly competitive market. These testable predictions are: (i) The imposition of a ME standard in a perfectly competitive market would predict an increase in the price of products that are close substitutes to those eliminated by the standard. On the other hand, in a market with imperfect competition in which firms have been engaging in second-degree price discrimination, the imposition of a more stringent ME standard would impose downward pressure on prices across the market, and in particular on mid- to low-end market segments; (ii) The predicted effect of a simultaneous change in both the ME and ES standards on the price of products that remain ES certified across the standard change is ambiguous in the imperfectly competitive market. However, an observed drop in these prices would be consistent with price discrimination and not perfect competition; and finally (iii) in an oligopolistic market, the imposition of a ME standard could stimulate expansion upward in the provision of efficiency in the market, and potentially increase product diversity on other dimensions besides efficiency as well. This would not necessarily be the case in a perfectly competitive setting. I show evidence consistent with an oligopolistic market structure for all three of these points.

The implication for these results is that, in addition to negative environmental externalities, energy efficiency regulation directly addresses a second market failure imposed by market power and the resulting under-provision of, and overcharging for, energy efficiency relative to the social optimum. Additionally, because of this market failure, the imposition of increasingly stringent regulation does not necessarily result in the short-run trade-off of higher consumer prices generally assumed in current federal ME standard regulatory impact analyses. This point has important implications for projected welfare effects of regulation, both in terms of greater welfare gains, as well as a redistribution of the costs of regulation away from consumers towards producers.

This paper will proceed as follows. Section I provides background on the history of energy efficiency regulation at the federal level in the US; section II presents the price-discrimination model and discusses the predictions for how the comparative static effect on prices and product provision differ between the competitive and oligopolistic cases across the market; section III discusses the data; section IV demonstrates the empirical results of the average drop in prices in the clothes washer market concurrent with the new standard effective dates; section V presents results from empirically testing the specific model predictions by looking at the heterogeneous effects of the standard changes across different market segments; and finally section VI concludes.

I. Policy Background

In 1975 the Energy Policy and Conservation Act (EPCA) laid the initial groundwork at the national level for a variety of energy efficiency measures including test procedures, labels and targets. EPCA was amended in 1979 to include energy efficiency standards to be established by the Department of Energy (DOE). In 1987 the National Appliance Energy Conservation Act (NAECA) established legislation stipulating that the minimum efficiency benchmark be periodically increased for a variety of appliances sold in the US. Further legislation, including the Energy Policy Act (EPAct) of 1992, as well as EPAct of 2005, and the Energy Independence and Security Act (EISA) of 2007 have continued to extend the number of products subject to standards, as well as update standards, test procedures, and review schedules.

Clothes washers were among the initial set of products for which ME standards were established through NAECA; in 1987 Congress adopted the first federal standard for clothes washers to be effective in 1988. DOE adopted the second federal clothes washer standard in 1991, which went into effect in 1994. This analysis focuses on the third federal clothes washer standard, which was adopted by DOE in 2001, and went into effect in a two-tier process. The first phase was effective on January 1st, 2004, and the second phase on January 1st, 2007. Also in 2007, the fourth federal clothes washer standard was adopted by Congress, but would not be effective until 2011.

Clothes washers are also subject to the ES label. This is not a restrictive standard, but rather establishes a benchmark of efficiency above which products qualify for the ES label, signaling a model as highly efficient to potential customers.

Table 1 provides a breakdown of the federal ME and ES standards for clothes washers enacted between 1991 and 2007. Before 2004, the ME standard was based on the Energy Factor (EF), which measures efficiency in terms of cubic feet per kWh per cycle. In 2004 the criteria for meeting the ME standard became based on the Modified Energy Factor (MEF). The MEF, also measured in cubic feet per kWh per cycle, expanded upon the EF by incorporating the energy required to dry moisture remaining in the clothing following the final spin cycle. Similarly, starting in 2001 the ES benchmark (only established for standard-size models) was based off of the MEF. Beginning in 2007, the ES benchmark also became contingent on the Water Factor (WF), which is the number of gallons per cycle per cubic foot used by the washer.

Table 1—US Federal Clothes Washer ME and ES Standards between 1991 and 2007

Year Adopted	Year Effective	Compact (TL)	Standard (TL and FL)	ES Requirment
1991	1994	EF≥0.9	EF≥1.18 (TL only)	-
1997	2001	-	-	MEF≥1.26
2001	2004	MEF≥0.65	MEF≥1.04	MEF≥1.42
2001	2007	(no change)	MEF≥1.26	MEF≥1.72 WF≥8.0

Note: This table shows adoption and effective years of the federal ME and ES standards between 1991 and 2007. The standards are set based on the energy factor (EF), modified energy factor (MEF), and water factor (WF). While the standards for clothes washers differ between compact and standard-size models, the majority (approximately 99 percent) of observations in my data are standard-class (capacity greater than 1.6 cubic feet).
Source: http://www.energystar.gov and http://www.appliance-standards.org/national

II. Model

There is an extensive theoretical literature discussing price discrimination with quality differentiation in imperfectly competitive markets. The classic case is a monopoly engaging in second-degree price discrimination. This form of price discrimination induces consumers to reveal otherwise unobservable information about their preferences for a quality characteristic of a product by structuring options and prices such that consumers sort themselves into purchasing the product that targets their willingness to pay for that characteristic. In this way the monopolist can extract more consumer surplus than if they supplied only one product type, or the socially optimal menu of products. Mussa and Rosen (1978) provide the original model with a monopoly supplier and a continuous distribution of consumer preferences for quality.

In section II.A I restate the basic model of a price discriminating monopolist, and the predictions of how a ME standard change alone will affect prices; in section II.B I discuss the implication of the market being oligopolistic or monopolistically competitive, rather than monopolistic; in section II.C I discuss the implication of the ME and ES standards changing simultaneously; and finally, in section II.D I summarize the predictions of the model.

A. *Monopoly Price Discrimination and Minimum Efficiency Standard Change*

I present here a simple reproduction, with N discrete types of consumers, of the key aspects of the classic Mussa and Rosen (1978) monopoly price discrimination model, pulling heavily from the characterization used by others (e.g., Donnenfeld and White 1988; Ronnen 1991; Fischer 2005; Houde 2012).I then outline, following Fischer (2005), the result of imposing a ME standard in this model.

Assume consumers have unit demand for a good, here an energy consuming durable such as a clothes washer. Assume N types of consumers – low (type 1) to high (type N) – characterized by having different levels of willingness to pay for efficiency; assume θ^k is the valuation of consumer type k for efficiency where, without loss of generality, $\theta^1 < ... < \theta^N$. In equilibrium there will be N models of clothes washers provided by the market, indexed by j, which vary in efficiency (e_j) and price (p_j). Equation 1 shows the utility of consumer type k for model j.

$$U_{kj} = \theta^k e_j - p_j \tag{1}$$

Suppose there are M consumers and $s_k M$ have valuation θ^k, where $\sum_{k=1}^{N} s_k = 1$. The monopolist does not observe a consumer's type, so they cannot perfectly price discriminate. Assume the cost of producing energy efficiency level e_j is $c\left(e_j\right)$, and that $c\left(e_j\right) \geq 0$, $c'\left(e_j\right) \geq 0$ and $c''\left(e_j\right) > 0$.[1] Note that I'm using k to index consumer types and j to index model types. In equilibrium each model type will correspond to one consumer type, so k and j will be equivalent. At this point I make this explicit by indexing everything by j.

A social planner would choose the efficiency levels of their menu of products to maximize total welfare. They would therefore solve the optimization problem presented in equation 2.

$$\max_{e_1,\ldots,e_N} W = \sum_{j=1}^{N} s_j \cdot \left(\theta^j e_j - c\left(e_j\right)\right) \tag{2}$$

The solution to the social planner's problem is $p_j^* = c'\left(e_j^*\right) = \theta^j,\ \forall j \in \{1, ..., N\}$. This implies that the social planner would choose to increase the efficiency for each model up until the point that the marginal cost of producing that level of efficiency just equals the marginal consumer valuation. In a perfectly competitive setting with free entry of new firms, price above marginal cost would result in excess supply, so the socially optimal prices are also equal to marginal cost.

Now I turn to the monopoly case. The monopolist picks the levels of efficiency and price (e_j, p_j) for each of the N models it supplies in order to extract the

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[1] The choice of a strictly convex cost of quality (or alternatively a concave-in-quality objective function) is a necessary condition for a separating price discrimination equilibrium to be optimal for the monopolist (Salant 1989).

maximum consumer surplus from all N types of consumers. If the monopolist could perfectly price discriminate, they would have an incentive to provide the social welfare maximizing level of efficiency, and would set price such that each consumer would just be indifferent between purchasing and not purchasing the product. However, if the monopolist cannot *ex ante* identify a consumer's type, this outcome would not be an equilibrium.

In the case where the monopolist cannot identify which type of consumer is which, they will engage in imperfect – or second-degree – price discrimination. The monopolist chooses the efficiency levels and prices of the N types of models they supply by maximizing their profit subject to the IR_j and ICj_k constraints for all j and $k \neq j$ types of consumers, where IR_j refers to the Individual Rationality (IR) constraint for the type j consumer, guaranteeing that all consumers will participate in the market,[2] and ICj_k refers to the Incentive Compatibility (IC) or self-selection constraint, assuring that consumer type j will be unwilling to purchase product type $k \neq j$ in equilibrium. In a separating equilibrium (i.e. $p_j \neq p_k$ and $e_j \neq e_k \, \forall j \neq k$), then $\theta^1 < ... < \theta^N$ implies that IR_1 and $ICj_{j-1} \, \forall j \in \{2, ..., N\}$ are binding while all other IR and IC constraints are non-binding.The monopolist's problem simplifies to that shown in equation 3.

$$
\begin{aligned}
(3) \qquad & \max_{p_1,\ldots,p_N,e_1,\ldots,e_N} \pi = \sum_{j=1}^{N} s_j \cdot (p_j - c(e_j)) \\
& s.t. \\
& IR_1 : \theta^1 e_1 - p_1 = 0 \\
& ICj_{j-1} : \theta^j e_j - p_j = \theta^j e_{j-1} - p_{j-1}, \forall j \in \{2, ..., N\}
\end{aligned}
$$

The solution for the monopolist, $(\bar{e}_j, \bar{p}_j)$, under second-degree price discrimination is presented in equation 4.

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[2] The monopolist may find it more profitable to only sell to a subset of consumer types, in which case the IR constraint for all types would not hold. For the time being I assume away this case.

$$c'(\bar{e}_j) = \begin{cases} \theta^j - \frac{\sum_{k=1}^{j+1} s_k}{s_j}\left(\theta^{j+1} - \theta^j\right) & \text{if } j \in \{1, ..., N-1\} \\ \theta^j & \text{if } j = N \end{cases} \tag{4}$$

$$\bar{p}_j = \begin{cases} \theta^j \bar{e}_j & \text{if } j = 1 \\ \bar{p}_{j-1} + \theta^j \left(\bar{e}_j - \bar{e}_{j-1}\right) & \text{if } j \in \{2, ..., N\} \end{cases}$$

These results, as originally demonstrated by Mussa and Rosen (1978), indicate that the second-degree price discriminating monopolist distorts downward the efficiency of all but the highest type products relative the social welfare maximizing case. At the same time they charge more for a given level of efficiency compared to the welfare maximizing case.[3] In addition this price differential is higher for higher levels of efficiency.

I now turn to a scenario in which a ME standard is imposed. This reproduces the same result as others who have discussed ME standards in a market facing this type of price discrimination (e.g., Fischer 2005). Assume in this simple example that the ME standard requires that the monopolist only supply products with efficiency level greater than or equal to the socially optimal efficiency level for the lowest type of consumer (i.e., the ME standard requires that $e_j \geq e_1^* \; \forall j \in \{1, ..., N\}$). Note that this is a binding constraint for the monopolist. For simplicity I assume the standard is non-binding for all other efficiency levels.

The new monopoly solution of optimal price and efficiency levels given the standard is presented in equation 5.

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[3] For example, note that $p_2^*(e_2) = \theta^2 e_2 = \theta^2 e_1 + \theta^2(e_2 - e_1)$ while on the other hand $\bar{p_2}(e_2) = \theta^1 e_1 + \theta^2(e_2 - e_1)$. Therefore, so long as $\theta^2 > \theta^1$, then for a given level of efficiency $\bar{p_2}(e_2) > p_2^*(e_2)$.

$$c'(e_j^S) = \begin{cases} \theta^j & \text{if } j = 1 \\ \theta^j - \frac{\sum_{k=1}^{j+1} s_k}{s_j}\left(\theta^{j+1} - \theta^j\right) & \text{if } j \in \{2, ..., N-1\} \\ \theta^j & \text{if } j = N \end{cases} \tag{5}$$

$$p_j^S = \begin{cases} \theta^j e_j^* & \text{if } j = 1 \\ p_{j-1}^S + \theta^j \left(e_j^S - e_{j-1}^S\right) & \text{if } j \in \{2, ..., N\} \end{cases}$$

The result is that $\frac{\partial e_1}{\partial Standard} > 0$; $\frac{\partial e_j}{\partial Standard} = 0 \; \forall j \in \{2, ..., N\}$; $\frac{\partial p_1}{\partial Standard} > 0$; and $\frac{\partial p_j}{\partial Standard} < 0 \; \forall j \in \{2, ..., N\}$. Although the type-1 customers face a price increase, it is offset by the increase in their utility from improved efficiency, so they are no worse off from a welfare perspective. Indeed, Ronnen (1991) states that while the model predicts an increase in prices for this segment in nominal terms, prices may actually drop in efficiency-adjusted terms. All customer types above the lowest are made strictly better off, as they receive the same level of efficiency as before, but at lower prices.

In the case of a perfectly competitive market on the other hand, the efficiency-price schedule would already be socially optimal. Therefore, imposing a binding standard would result in $\frac{\partial p_1}{\partial Standard} > 0$ and $\frac{\partial p_j}{\partial Standard} = 0$, $\forall j \in \{2, ..., N\}$. However, if the increase in price of the lowest efficiency group resulted in type-1 consumers substituting to higher efficiency levels, then this positive demand shock would potentially increase prices in higher efficiency segments as well.

B. Oligopoly Case

In the previous section I outlined the price effect of the ME standard changing in a monopolistic market. However, the clothes washer market in the US is better described as oligopolistic or monopolistically competitive. The top four or five manufacturers, including their brand subsidiaries, control between 93 and 98 percent of the market.[4] Whirlpool in particular controlled over 50 percent of the market on average in the period of this analysis according to the data used in this study.

There is a rich literature demonstrating that even when the monopoly assumption is relaxed to allow for duopoly, oligopoly, or monopolistic competition, the unregulated case still results in an inefficient range of quality, with a depression of quality on the low-end below the socially optimal level, and prices still higher than socially optimal. In particular Katz (1984) discusses a case with multiple firms each selling a range of product quality, and with market power due to brand loyalty. This brand loyalty is modeled as a premium incurred by consumers if they have to switch from their preferred brand. A key assumption is that consumers who are more quality-conscious are also more brand-conscious. In this setting, there are higher margins on the high-end segments of the market, and more competition in the low-end of the market. This means sales of high-end products are more profitable, and it is therefore more important to capture and maintain the loyalty of those consumers on the high-end relative to the low-end. For this reason, quality on the low-end is depressed downwards to prevent high types from switching down. Therefore, quality is depressed on the low-end in the non-monopoly imperfect competition case, and price margins still increase with quality. Indeed De Meza and Ungern-Sternberg (1982) demonstrate it can even be the case that a monopolistically competitive market result in an even wider range of quality and even higher prices than in the monopoly case.

Some more recent theoretical literature has returned to the price discrimination model and found some more ambiguous results when the market is oligopolistic (e.g., Armstrong and Vickers 2001; Rochet and Stole 2002; Fischer 2010). However, while there are some cases in which the equilibrium outcome is such that quality is not depressed on the low end, or price is not elevated on the high end, of

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[4] The top manufacturers of clothes washers are Whirlpool, General Electric, Maytag (before their merger with Whirlpool in 2006), Electrolux, and LG Electronics.

an unregulated oligopolistic market, these equilibria are not always unique (Armstrong and Vickers 2001), and are highly sensitive to the assumption that brand and quality preferences are uncorrelated (Armstrong and Vickers 2001; Rochet and Stole 2002). This is an empirical question, but the results when brand preference and quality are correlated do tend to be more consistent, and anecdotal evidence from informal discussions with people involved in the industry corroborates this description of the market. So, for now, I choose to defer to the earlier theoretical literature by Katz (1984) and others.

Others have demonstrated the theoretical impact of minimum quality standards on quality-differentiated markets that are oligopolistic or monopolistically competitive. In particular Ronnen (1991) develops a model of an industry in which multiple firms face quality-dependent fixed costs and compete in quality and prices. In this model, the introduction of a minimum quality standard causes high quality sellers to increase quality to alleviate price competition induced by the collapsing of the quality range on the low end. However, the assumption that $c''(e) > 0$ assures high quality producers raise quality less than the increase in quality on the low end induced by the minimum quality standard. This means price competition is intensified regardless of attempts by high-end firms to alleviate it, so in the end, prices (controlling for quality level) still drop. Crampes and Hollander (1995) extend the model developed by Ronnen (1991) by allowing the quality costs to be variable instead of fixed. They find the same qualitative results as did Ronnen, but while Ronnen showed that consumers necessarily gain from a minimum quality standard, Crampes and Hollander show that consumer welfare increases only if the high quality firm does not respond by raising quality too drastically.

Therefore, predictions for an oligopolistic or monopolistically competitive market are qualitatively consistent with the monopoly case, contingent on the assumption that consumers who care more about quality are also more likely to be brand-conscious. This implies that the monopoly model is a reasonable proxy for the non-monopoly imperfect competition setting.

In addition to the consistency of the price predictions between the monopolistic and oligopolistic models, the literature on oligopolistic price discrimination discusses an additional implication of imposing a minimum quality standard in such a setting. Ronnen (1991) and Crampes and Hollander (1995) derive that following a new minimum quality standard, imperfectly competitive producers have an incentive to expand quality upwards to increase the spread of quality in the market again following the new standard. They do this to alleviate the increased price competition between products imposed by the quality distribution collapse following the new standard. Realistically speaking, there is more than one quality dimension for products supplied in these markets, so I would suggest that this process by which firms attempt to reduce competition may be multifaceted; they may indeed expand the collapsed quality dimension upward (in this case increase the efficiency of products at the high end of the market following a ME standard restriction), but increased product differentiation could take place on other dimensions as well. Therefore, increased product diversity in general many be indicative of this process.

C. ENERGY STAR Standard Change

Here I discuss the implications of a change in the ES standard in the model with quality differentiated products. Houde (2012) explores the result of an isolated increase in the ES standard for refrigerators in 2008, in which case a change in the ES standard has distinct price predictions. In the setting when the ME standard is changing simultaneously, the ES standard changing primarily serves to muddle the predictions on the price for higher efficiency market segments.

Pulling somewhat from Houde (2012), you can see this by assuming consumers do not pay perfect attention to the efficiency level of the products they consider purchasing, and so e_j represents a composite of efficiency-relevant signals picked up by the consumer. One may be the true energy efficiency of the product, while another may be the ES status of the product, etc.

Products decertified from ES as a result of the ES standard change may be perceived as less energy efficient once they no longer have the ES label, even if the actual energy efficiency levels of the products have not changed. A decertification from ES might result in a negative demand shock, resulting in a drop in the price of these products. This would be true regardless of market structure, and so does not serve as a basis to empirically differentiate between competitive and price-discriminating markets.

For products that were ES certified both before and after the new standard, the model provides ambiguous price predictions. The prices of products that qualified for ES both before and after the new standard are not predicted to change in a perfectly competitive market. In the imperfectly competitive model however, the fact that consumers may perceive products that are decertified from ES as less energy efficient than before could allow producers to increase the prices of products that remain ES compliant, this is because $\frac{\partial p_j}{\partial e_{j-1}} < 0$ in the monopolistic price-discrimination model. However, the ME standard is putting downward pressure on the prices of these products as well, rendering the price prediction ambiguous. However, a drop in the price of products that remain ES compliant both before and after the standard is consistent with imperfect competition, though not with perfect competition.

D. Summary of Model Predictions

In summary, there are three primary predictions of the effect of a new ME standard in the imperfectly competitive model that are in contrast to the predictions implied by a perfectly competitive model: (i) The imposition of a ME standard in a perfectly competitive market would predict an increase in the price of products in the market, particularly those that are close substitutes to products eliminated by the standard. On the other hand, in a market with imperfect competition in which firms have been engaging in second-degree price discrimination, the imposition of a more stringent ME standard would result in downward pressure on prices across the market, and in particular on mid- to low-end market segments; (ii) The predicted effect of a simultaneous change in both the ME and ES standards on the price of products that remain ES certified is ambiguous in the imperfectly competitive market. However, an observed drop in these prices would be consistent with price discrimination and not perfect competition; and finally (iii) in an oligopolistic market, the imposition of a ME standard could stimulate expansion upward in the levels of efficiency supplied to the market, and potentially increase product diversity on other dimensions as well. This would not necessarily be the case in a perfectly competitive setting.

III. Data

I use point-of-sale data for clothes washers, dryers and room air conditioners (RACs) from NPD Group.[5] These data are acquired from an incomplete set of retailers in the US.[6] The data are aggregated to the national level and consist of monthly total revenue and total quantity sold observations by individual model number.

The NPD data for clothes washers were matched to energy usage data by model number and year from three sources: (1) the Federal Trade Commission (FTC) appliance energy database, (2) the ENERGY STAR database, and (3) the California Energy Commission (CEC) appliance energy database. The FTC data provide a measure of kilowatt-hours per year (kWh/year) energy usage, which corresponds to the Energy Guide label posted on products at the point of sale. Both the ENERGY STAR and CEC sources provide data on the EF, MEF and WF of products.[7] However, these latter sources cover a much smaller subset of the model numbers in the NPD data. The way in which I use these three energy use data sources is explained in more detail below.

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[5] NPD is not an acronym, but rather the name of the company: The NPD Group, Inc., The NPD Group/NPD Houseworld. Port Washington, NY.

[6] A list of participating retailers can be found in Appendix A.

[7] The EF, MEF and WF energy usage measures were defined in section I.

In order to control for changes in macroeconomic shocks to the appliance market, and to control for changes to the retailer mix in the NPD data over time, I use both dryers and RACs as counterfactual groups.[8] Neither dryers nor RACs had any energy-efficiency policy changes during the study period. However, both of these appliances are imperfect counterfactuals in some ways. First, RACs, while arguably a relatively independent product from clothes washers, did experience more general price volatility and were more prone to seasonal price variability compared to clothes washers. Second, dryers and washers are likely compliments, so their prices and sales should be positively correlated. Therefore the price effects of policies imposed on clothes washers measured relative to dryers will likely be underestimates.

The NPD data, while extensive in some ways, are imperfect in others. In particular, 40 percent of the observations had model numbers that were masked to ensure anonymity of the retailers. These observations therefore could not be matched to any of the energy usage data, and so had to be omitted from the analysis. Of the models that do have fully detailed model numbers, 12 percent of the observations were for model numbers not included in the FTC energy usage database, and therefore had to be omitted as well. In order to maintain comparability between clothes washers and the counterfactual appliance groups, masked model numbers were also dropped from the dryer and RAC data.

As mentioned in Section I, the energy measures used to determine the compliance of washer models with ME and ES standards in 2004 and 2007 are the MEF and WF. These efficiency measures are not available for many of the models in the NPD data during this period. The ENERGY STAR and CEC data do provide these measures for a subset of models, specifically those that were at some point labeled as ES, or were sold in California. This means the MEF and WF data are only available for relatively high-efficiency models, and so cannot reli-

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[8] Some retailers did enter or exit the data at different times in the series, however I was assured by NPD that the large retailers do not change over the study period.

ably be used to identify models that are made non-compliant with the new ME standards. However, they can more dependably identify whether or not models are ES qualified at various points in time. All models that could not be matched to the CEC or ENERGY STAR data are assumed to have never been ES qualified within the study period.

While the FTC kWh/year measure does not correspond directly to the MEF or WF used to set the standards, it is an important indicator of energy consumption, particularly from the perspective of the consumer purchase decision, as it is posted on products at the retail outlet to inform consumers about the energy use of their potential purchases. I use the FTC energy use measure to identify models that are likely to have been eliminated by the new ME standards. This categorization is not exact, but provides a roughly intuitive way of stratifying the market to explore heterogeneous price effects of changes in the standards. This process will be described in more detail in section V.

There are 594 unique clothes washer models, 820 unique dryer models, and 595 unique RAC models used in the analysis, summary statistics for which are provided in table 2. An individual appliance model number uniquely identifies a particular design. Therefore, controlling for model-specific fixed effects will likely control for more or less all relevant unobserved characteristics of the models from a consumer perspective. If a major characteristic changes, then this is likely to result in a new unique model number.

Looking more closely at the summary statistics in table 2, recall that the changes to clothes washer standards occurred on January 1st, 2004, and January 1st, 2007. The real prices of clothes washers and dryers have risen on average between 2003 and 2007: approximately 5.3 percent for clothes washers and 26.8 percent for dryers. On the other hand, the average real prices of RACs went down slightly (approximately 6.5 percent) over this time period. The FTC kWh/year energy use of clothes washers has significantly decreased over this period, with a 56.3 percent reduction between 2003 and 2007. Additionally, the prevalence

Table 2—Summary Statistics

	2003	2004	2005	2006	2007
Dryer Price	465.2	519.8	537.3	548.6	589.7
	(204.5)	(265.9)	(248.8)	(249.1)	(257.3)
Number of Dryer Models	254	219	305	358	444
RAC Price	391.8	335.8	334.3	359.8	366.5
	(219.1)	(210.2)	(210.1)	(211.7)	(217.8)
Number of RAC Models	295	219	277	243	211
CW Price	648.9	694.9	714.6	707.0	683.5
	(397.9)	(416.8)	(397.8)	(382.8)	(338.0)
CW kWh per year	714.1	446.9	392.9	368.0	311.6
	(275.4)	(192.8)	(161.1)	(154.1)	(133.1)
Number of CW Models	159	237	228	241	355
Share CW FL	0.18	0.26	0.33	0.37	0.46
Share FL ES	0.29	0.75	0.83	0.88	0.90
Share TL ES	0.05	0.10	0.16	0.21	0.11

Note: This table shows annual averages (and standard deviations) of prices and energy consumption, as well as model counts, between 2003 and 2007 for the three products used in this analysis: clothes washers (CW), dryers, and room air conditioners (RAC). In addition, the share of CW models that are front load (FL); the share of FL models that are ES qualified; and the share of top load (TL) models that are ES qualified are shown for each year as well. Recall the minimum and ES standards changed for CW at the beginning of 2004 and 2007, while no energy efficiency policies affected RAC or dryer during this period.
Source: Author calculations.

of front-loading washer models has steadily increased over time, making up 18 percent of observations in 2003 and increasing to 46 percent in 2007. Finally, while the prevalence of ES qualification has increased for both front- and top-load machines over this time period,[9] it has generally been the case that front-load washers are much more likely to be ES qualified than top-load washers.

Figure 1 shows the price trends – both on average and within-model – of the three appliances used in this analysis between 2002 and 2009, normalized to average prices in January 2002. Of particular interest in this figure is that the within-model prices drop steadily over this time period for all three appliances,

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[9] Note that the indicator of ES qualification is a proxy based on imperfect MEF and WF data, therefore the low rates of qualification, particularly in 2003, may be an artifact of the data.

though less so for RACs. Note also the visible price drop, downward break in trend, or both, at both standard change dates for clothes washers (indicated by the vertical lines) but not for dryers or RACs. The next section quantifies these price effects.

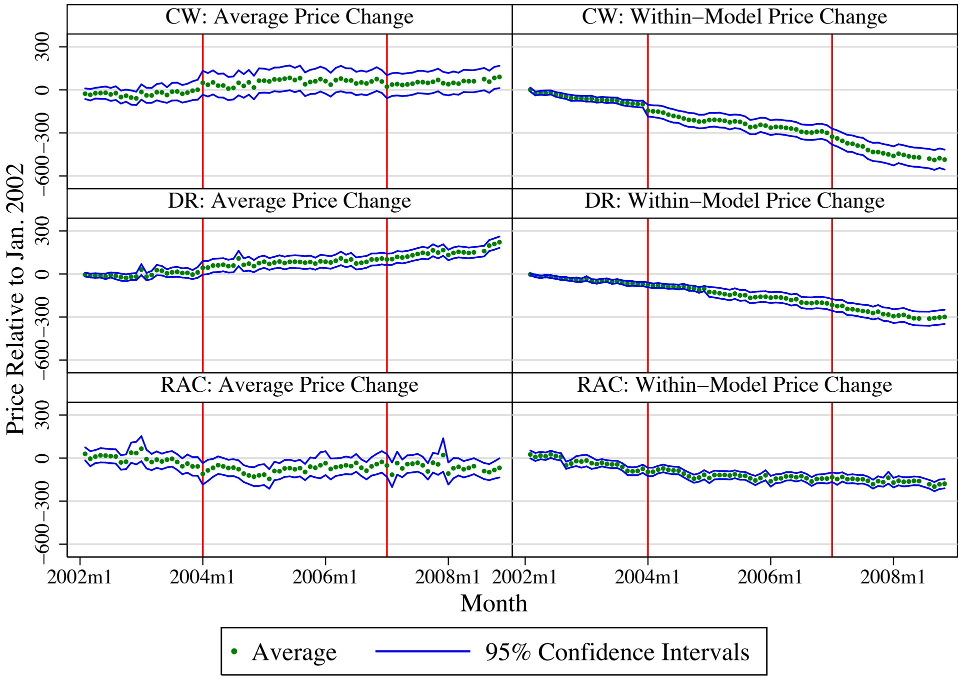

Figure 1. Market Average and Within-Model Price Trends

Note: This figure shows the price trends, both on average (left-hand panels), and within-model (right-hand panels) between 2002 and 2009 of the three products used in this analysis: clothes washers (CW), dryers (DR), and room air conditioners (RAC). The trends are shown relative to the average prices of the products in January 2002, which were $653.3 for CW, $442.7 for DR, and $424.3 for RAC. All prices are deflated using the consumer price index to December 2009 prices. The effective dates of the two changes in the clothes washer standards are indicated by the vertical lines. Data from July 2008 was dropped in generating these figures, as the price data in that period was an extreme outlier and appears to be an anomaly.
Source: Author calculations.

IV. Results: Average Price Effects

In this section I estimate the market-average short-run price effect at the time of the combined ME and ES standard changes for clothes washers. I limit all of the analysis in the remainder of the paper to one year prior to the standard change and one year after.[10]

In order to quantify the effects shown graphically in figure 1, I use two estimation strategies. First, I model time as flexibly as possible by including dummy variables for each appliance-time-period (equation 6), and second I impose a linear time-trend assumption on prices (equation 7). In the former case, time is accounted for extremely flexibly, and no structure is imposed on the prices over time, however the price effect of the standard is primarily estimated off of the differences between prices in the month just prior to and the month in which the new standard became effective, and so is sensitive to any anomalous shocks in these two months. In the latter case, I allow the linear trend to differ across appliances and to change at the standard effective date. Even given this, the assumption of a linear price trend is relatively restrictive. However, it does allow an estimation of the effect of the standard on the rate of change of prices over time, as well as on the level change.

The first estimation strategy is presented in equation 6. In this equation p_{it} is deflated price at time t of model i. The variable T_i is a dummy variable equal to one if the observation is for an appliance affected by the standard (clothes washers) and equal to zero otherwise (dryers or RACs). The term $Standard_t$ is a dummy variable that turns on at the time the new standard takes effect. The term τ_t represents a set of dummy variables for each time-period in the sample (with the month prior to, and the month of the standard change omitted). I run the regressions with and without fixed effects and with and without each of the counterfactual appliances. In the regressions with fixed effects the term μT_i is omitted; in the regressions without fixed effects γ_i is omitted; and for regressions

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[10] I limit the analysis to one year both before and after the policy change in order to isolate the analysis from other policy changes, and because the short-run is the most relevant lens for testing the imperfect competition price-discrimination model predictions presented in section II.

with no counterfactual group $\beta_2 = \mu = 0$.

$$p_{it} = \alpha + \mu T_i + \beta_2 Standard_t + \delta T_i \cdot Standard_t + \tau_t + \tau_t \cdot T_i + \gamma_i + \varepsilon_{it} \tag{6}$$

The second estimation strategy is presented in equation 7. In this equation p_{it}, T_i and $Standard_t$ are defined as above. Additionally, the term $Trend_t$ is a linear time trend. In the regressions with fixed effects the term μT_i is omitted; in the regressions without fixed effects γ_i is omitted; and for regressions with no counterfactual group $\beta_1 = \beta_2 = \beta_3 = \mu = 0$.

$$\begin{aligned} p_{it} = & \alpha + \mu T_i + \beta_1 Trend_t + \beta_2 Standard_t + \beta_3 Standard_t \cdot Trend_t \\ & + \psi T_i \cdot Trend_t + \delta T_i \cdot Standard_t + \phi T_i \cdot Standard_t \cdot Trend_t \\ & + \gamma_i + \varepsilon_{it} \end{aligned} \tag{7}$$

The coefficients of interest are the coefficients on $T_i \cdot Standard_t \cdot Trend_t$ and $T_i \cdot Standard_t$. The coefficient on $T_i \cdot Standard_t$ is interpreted as the discontinuous level change, in dollars, of the price at the effective date of the new standard, and the coefficient on $T_i \cdot Standard_t \cdot Trend_t$ is interpreted as the change in the average incremental amount, in dollars, by which prices rise or fall each month following the standard relative to before the standard. In the regressions with a counterfactual, the effects are interpreted relative to the counterfactual.

Panel A of table 3 shows the results without fixed effects using the first estimation strategy with appliance-specific time effects, while panels B and C show the results with fixed effects using the first and second estimation strategies, respectively. In all cases I present three sets of regression results. Columns 1 and 4 present the results including CW alone; columns 2 and 5 present the results of the difference-in-differences (DD) regressions including dryers as the counterfactual, and finally columns 3 and 6 present the results of the DD regressions including

RACs as the counterfactual. Columns 1 trough 3, and 4 through 6, show the results from the 2004 and 2007 standard changes, respectively.

The average market price results in panel A of table 3 indicate that there is no consistent evidence of a statistically significant change in average market prices at the time the 2004 standard came into effect for clothes washers.[11] In 2007 there is some evidence that average prices dropped for clothes washers by around \$44 concurrent with the standard change. If the change in standard only resulted in relatively inexpensive low-efficiency models being eliminated, the average market price would increase. These results point to the presence of some other price adjustment.

Panels B and C of table 3 demonstrate that within-model prices discontinuously dropped significantly by between \$34 and \$72 in 2004 and \$15 and \$32 in 2007 on average, depending on the specification. Additionally, in panel C there is evidence that prices began trending downward more quickly after the standard changes relative to before. The magnitude of this incremental increase in the rate of change of the downward trend in within-model prices was around \$3 per month after the 2004 standard change and between \$4 and \$7 per month following the 2007 standard change.

As can be seen in figure 1, the prices of RACs (both on average and within-model) are more volatile and seasonally cyclical compared to the other two products. It is for this reason that the results presented in panels B and C of table 3 relative to RACs vary the most. I am more inclined to favor the estimation strategy using the linear time trend for the case of RACs as the counterfactual, as this specification is less sensitive to a random one-month shift in RAC prices.

In sum, the effect on average market prices was somewhat inconsistent, but there is some evidence that prices dropped on average at the time of the 2007 standard change. Within-model prices consistently demonstrated evidence of both a

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[11] The average price of RACs dropped in January 2004, but jumped quickly back up again, so the large significant estimate on $T \cdot Standard$ in column 3 of panel A in table 3 is based on a one-month drop in the RAC prices that did not persist.

Table 3—Average Price Effect at New Standard Effective Date

Dependent Variable:	2004 Standard Change			2007 Standard Change		
Price	no Control	T=0: Dryers	T=0: RAC	no Control	T=0: Dryers	T=0: RAC
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Average Price Effects at New Standard Date with Month Effects						
T		179.2***	288.7***		151.0***	330.6***
		(37.38)	(40.80)		(30.43)	(36.65)
Standard		32.13	-52.17*		-2.995	-16.88
		(21.03)	(27.94)		(9.311)	(27.57)
TxStandard	48.26	16.12	100.4**	-44.27***	-41.28**	-27.39
	(36.00)	(41.68)	(45.57)	(16.43)	(18.87)	(32.10)
Constant	646.1***	466.9***	357.4***	711.5***	560.5***	380.9***
	(33.04)	(17.51)	(23.95)	(26.30)	(15.34)	(25.52)
Model fixed effects	-	-	-	-	-	-
TxTime fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.006	0.070	0.167	0.001	0.045	0.200
Panel B: Within-Model Price Effects at New Standard Date with Month Effects						
Standard		-6.534	-21.55**		-13.21***	3.106
		(5.471)	(10.17)		(3.411)	(8.946)
TxStandard	-44.01***	-37.47***	-22.45	-28.84***	-15.63**	-31.95***
	(11.86)	(12.97)	(15.66)	(6.806)	(7.608)	(11.28)
Constant	693.2***	592.3***	552.4***	746.1***	663.8***	620.0***
	(7.095)	(4.064)	(5.057)	(5.530)	(3.175)	(4.277)
Model fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
TxTime fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.238	0.214	0.240	0.324	0.305	0.303
Panel C: Within-Model Price Effects at New Standard Date with Linear Trend						
Trend		-3.600***	-7.083***		-5.159***	-2.328***
		(0.548)	(0.905)		(0.648)	(0.795)
Standard		-1.683	36.10***		-2.954	14.50*
		(4.290)	(7.230)		(4.202)	(7.629)
TrendxStandard		0.413	0.762		-2.438**	-0.744
		(0.974)	(1.171)		(0.984)	(1.306)
TxTrend	-4.342***	-0.743	2.741**	-5.754***	-0.595	-3.426***
	(0.815)	(0.976)	(1.220)	(0.835)	(1.056)	(1.158)
TxStandard	-36.58***	-34.90***	-72.68***	-13.23**	-10.28	-27.73***
	(11.16)	(11.87)	(13.34)	(6.383)	(7.639)	(9.981)
TxTrendxStandard	-3.054***	-3.468**	-3.816**	-7.079***	-4.641***	-6.335***
	(1.098)	(1.461)	(1.609)	(1.371)	(1.687)	(1.901)
Constant	791.2***	682.0***	669.9***	1,075***	975.1***	885.3***
	(20.15)	(11.24)	(13.47)	(48.17)	(29.54)	(35.55)
Model fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
TxTime fixed effects	-	-	-	-	-	-
R-squared	0.235	0.209	0.223	0.319	0.300	0.293
Observations	3,637	7,283	6,422	4,793	10,655	7,129
Number of Models	418	736	790	431	959	751

Note: This table shows the regression results of the change in price of clothes washers concurrent with the January 1st, 2004 and January 1st, 2007 standard changes. The dependent variable is price deflated using the consumer price index. The term "T" is an indicator variable for clothes washers. The term "Standard" is a dummy variable that changes from zero to one starting on the standard effective date. The term "Trend" is a linear time trend. Columns 1 and 4 show price change within clothes washers, while the rest of the specifications are relative to dryers (columns 2 and 5) or room air conditioners (RACs; columns 3 and 6). Standard errors clustered at the model-number level are shown in the parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.
Source: Author calculations.

significant drop in level, and increased downward trend at both standard changes.

V. Results: Market-Segment Heterogeneity

The previous section demonstrated that there was a clear drop in the within-model price on average, both in the form of a level drop and a increasingly rapid downward trend, at the time of both the 2004 and 2007 standard changes. Why might this price drop have occurred? To answer this question, I present empirical tests of the price discrimination model predictions presented in section II.

The initial step in this process is to characterize relevant market segments. As I will demonstrate, the clothes washer market is made up of three primary market strata: front-load washers are the most efficient, followed by mid- to high-efficiency top-load washers, and finally low-efficiency top-load washers make up the bottom of the market.

Figure 2 shows the distribution of kWh/year observations for clothes washers in the the year just prior to and the year just following the two standard changes examined here. The distributions of front-load and top-load washers are shown separately. I identify cut-offs for top-load models based on these distributions. These cut-offs are 700 and 520 kWh/year in 2004 and 2007, respectively. They are indicated by the vertical lines in the bottom two panels of figure 2. I posit that the new standard is most likely to be binding for those models above the cut-off. There are two additional observations of note in figure 2. First, front-load washers are significantly more efficient than top-load washers in general. Second, the 2004 standard change resulted in a relatively large shift in the energy use distribution for top-load washers. In contrast, the incremental shift following the 2007 standard change was less extreme.

Categorizing products based on observable energy-efficiency characteristics results in nine categories: (1) front-load models that span the standard change (FL); (2) front-load models that exit the market prior to the standard change (FL Exit); (3) front-load models that enter the market following the standard

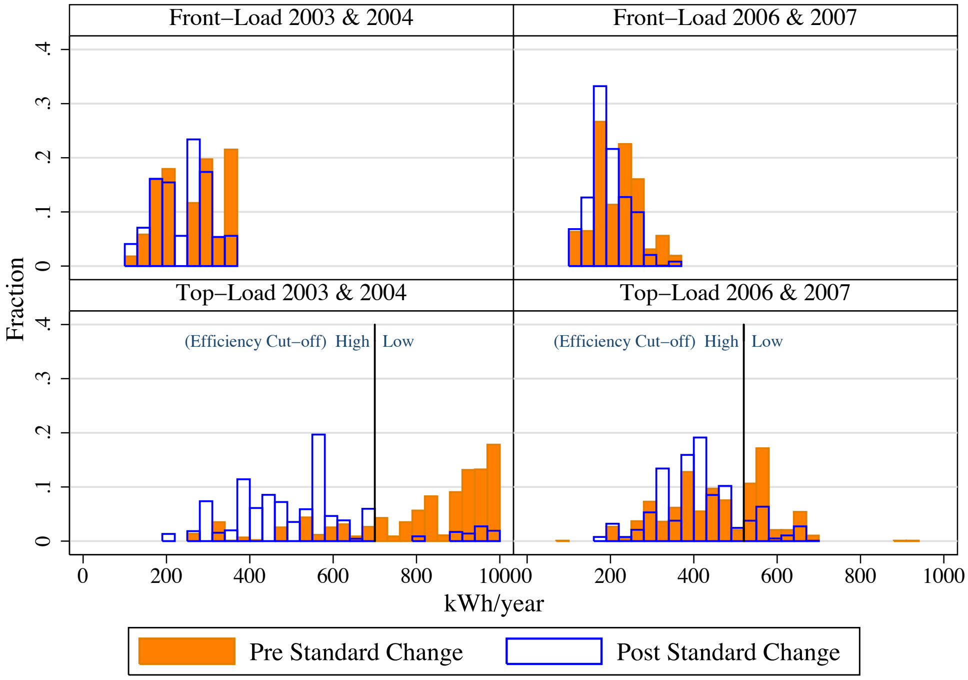


Figure 2. Categorization of Low- and High-Efficiency Clothes Washer Models

Note: This figure shows the distribution of annual energy consumption (based on the FTC kWh/year usage measure) for the year just prior to (solid histograms) and the year just following (outlined histograms) the two standard changes. The 2004 standard change case is shown in the left-hand panels, while the 2007 case is shown in the right-hand panels. The distributions for front-load models are shown in the top two panels, while the top-load model distributions are shown in the bottom two panels. Using these distributions, I define a cut-off value of annual energy consumption (700 kWh/year in 2004 and 520 kWh/year in 2007) such that models consuming more than this are defined as "low-efficiency" and are more likely to have been eliminated by the standard change.
Source: Author calculations.

change (FL Enter); (4) top-load models that remain in the market and remain ES qualified across the standard change (TL ES); (5) top-load models that were ES qualified and remain in the market across the standard change, but become decertified from ES qualification as a result of the standard (TL Decert.); (6) relatively high-efficiency non-ES top-load models that span the standard change, were below the cut-off defined in figure 2 prior to the standard change, and were therefore not likely to have been directly eliminated by the standard (TL High EE); (7) relatively low-efficiency non-ES top-load models that span the standard change, were above the established cut-offs, and therefore were more likely to have been directly eliminated by the standard (TL Low EE); (8) top-load models that exit the market prior to the standard change (TL Exit); and finally, (9) top-load models that enter the market following the standard change (TL Enter).

Table 4 provides summary information for each of these nine groups. Two key observations from this table are: (i) Most, though not all, products in the TL Low EE group are eliminated by the standard. Particularly in 2004 close to 15 percent of the TL Low EE models were still in the market a full year after the standard was changed; and (ii) while almost all front-load models that enter the market just following either standard change are ES qualified, only 16 percent in 2004 and 12 percent in 2007 of the many top-load models that enter the market following the standard change are ES qualified. This is indicative of a pattern I will elucidate further bellow, that new top-load models are introduced to maintain the low-end of the market, while new front-load models are introduced to spread the high-end of the market upward.

Figure 3 shows the trends in (i) average real price; (ii) average within-model efficiency-adjusted price; and (iii) annual energy consumption, of the nine groups defined in table 4. From this set of graphs the market categorizations are further clarified. The front-load models make up the top of the market both in terms of energy consumption (lowest) and price (highest). The mid-range top-load models are mid-range both in terms of price and energy consumption, and the low-end

Table 4—Characterization of Market Segments

	FL	FL Exit/ Enter	TL ES	TL De-cert.	TL High EE	TL Low EE	TL Exit/ Enter
				Panel A: 2003/2004			
Unique models	14	12/46	0	0	14	35	84/128
kWh/year 2003	237	280	-	-	499	923	814
	(74)	(58)			(145)	(66)	(175)
kWh/year 2004	215	244	-	-	426	731	492
	(58)	(58)			(140)	(202)	(131)
Price 2003	1193	991	-	-	706	510	544
	(346)	(292)			(592)	(201)	(324)
Price 2004	1091	1165	-	-	688	440	542
	(340)	(398)			(543)	(174)	(272)
Percent ES	29	50/98	-	-	7	0	10/16
Percent exited by 2005	36	20	-	-	57	86	24
				Panel B: 2006/2007			
Unique models	76	14/76	10	17	54	37	33/85
kWh/year 2006	214	217	252	371	421	576	485
	(52)	(51)	(42)	(109)	(48)	(43)	(147)
kWh/year 2007	202	183	262	402	415	581	388
	(46)	(36)	(45)	(108)	(48)	(49)	(69)
Price 2006	1046	818	761	565	545	401	565
	(336)	(284)	(175)	(153)	(283)	(86)	(483)
Price 2007	879	931	687	491	492	357	516
	(331)	(300)	(219)	(153)	(227)	(87)	(239)
Percent ES	97	57/99	100	-	0	0	18/12
Percent exited by 2008	30	13	0	47	59	95	25

Note: This table characterizes the nine categories of products I define: front-load models that span the standard change (FL); front-load models that exit (enter) the market prior to (following) the standard change (FL Exit/Enter); top-load models that remain in the market and ES qualified across the standard change (TL ES); top-load models that were ES qualified and remain in the market across the standard change, but become decertified from ES qualification as a result of the standard change (TL Decert.); relatively high-efficiency non-ES top-load models that span the standard change and are not likely to have been directly eliminated by the standard (TL High EE); relatively low-efficiency non-ES top-load models that span the standard change and are more likely to have been directly eliminated by the standard (TL Low EE); and finally, top-load models that exit (enter) the market prior to (following) the standard change (TL Exit/Enter). While the table indicates that there were no TL models that remained ES qualified and in the market across the 2004 standard change, in actuality in the data there was one model that was in this category. However, given that the variable is only a proxy for ES certification, only one model in that category is within the margin of error for that category definition. I chose to include this one model in the TL High EE group in 2004 instead. The numbers in parentheses are standard errors of the mean price and kWh/year measures.
Source: Author calculations.

top-load models are both the cheapest, and the least efficient.

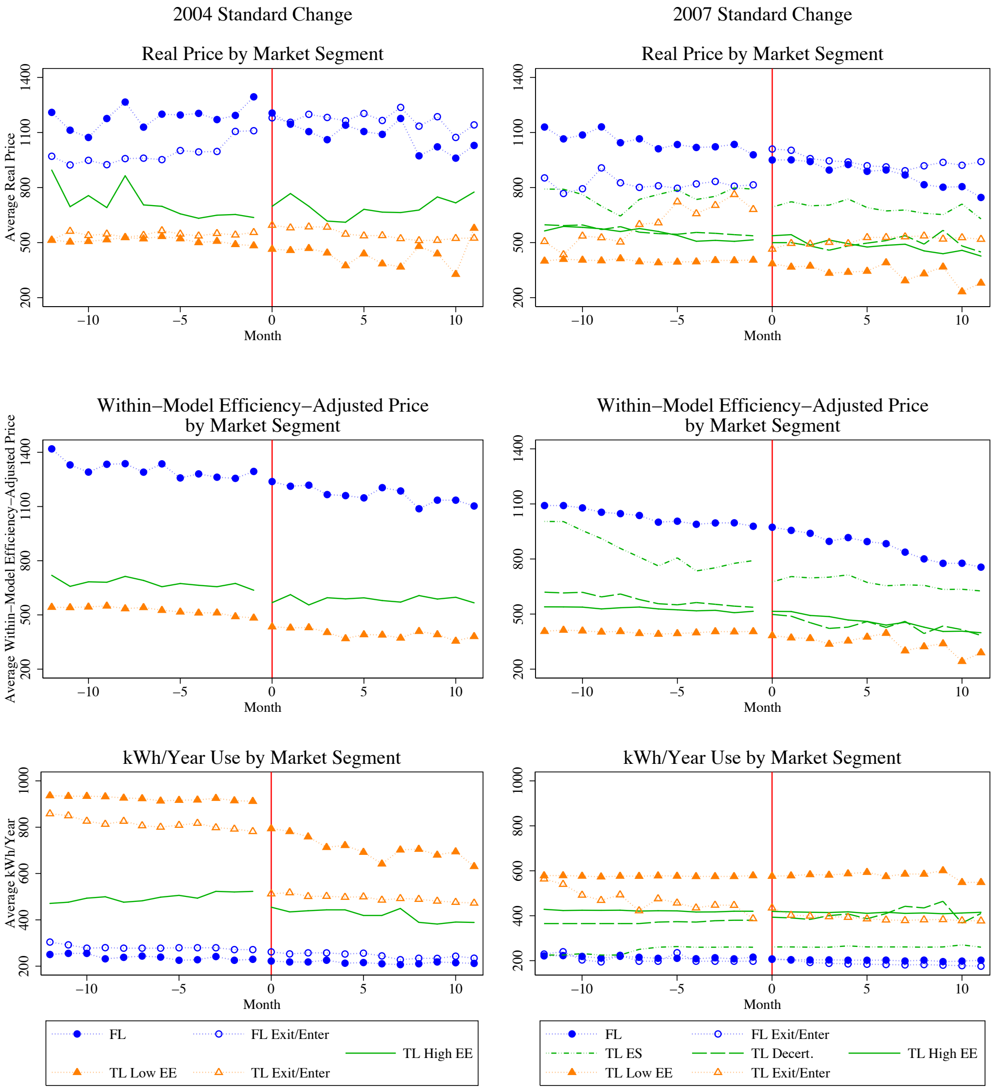
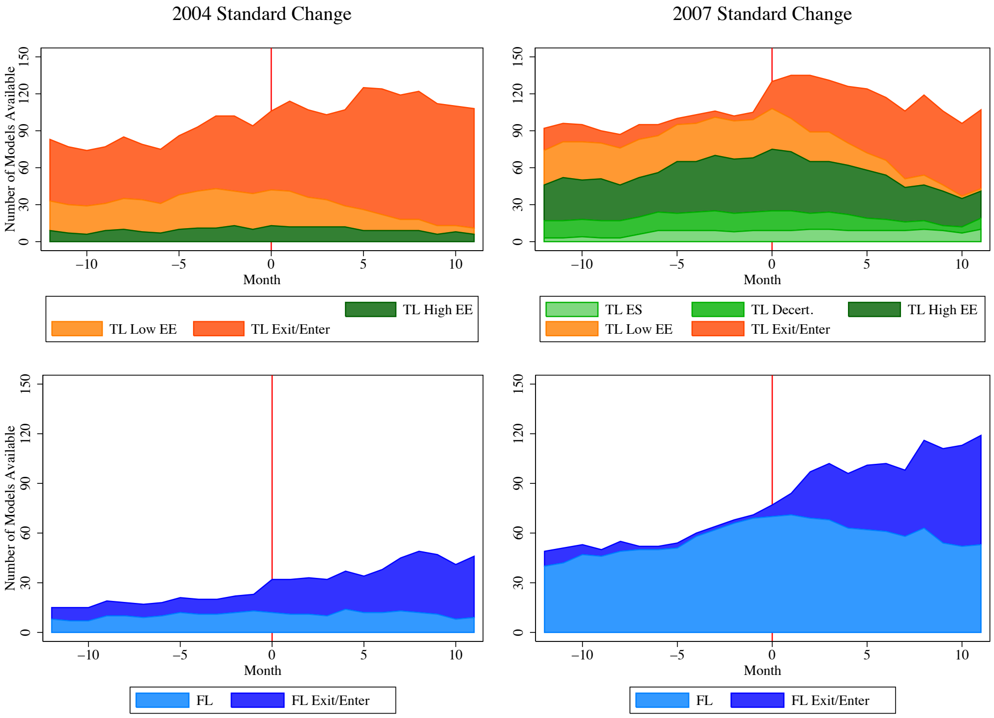


FIGURE 3. HETEROGENEOUS PRICE AND ENERGY-USE SHIFTS AT STANDARD EFFECTIVE DATES

Note: This figure shows the average price trends (top two panels); within-model efficiency-adjusted price trends (middle two panels); and average annual energy use (bottom two panels), of the nine market segments defined in table 4. The trends around the 2004 standard change are shown in the left-hand panels, while those for the 2007 standard change are shown in the right-hand panels. The veritical lines at month 0 indicate the months each standard came into effect. All prices are deflated using the consumer price index to December 2009 price levels.
Source: Author calculations.

Focusing on the annual energy consumption graphs in the bottom two panels of figure 3, it is clear that the 2004 standard precipitated a notable drop in annual energy consumption of available models at the bottom of the market. Existing TL Low EE models increased in efficiency, and models introduced following the standard change were significantly more efficient than those dropping out of the market the year before. The change in annual energy consumption at the 2007 standard effective date was less extreme, coming primarily in the form of inefficient models dropping out of the market leading up to January 1st, 2007. Looking broadly at the price changes around the standard effective dates, of note is that while there is some reorganization leading up to the standard, the imposition of the new standard is followed by a clear re-establishment of market ranking. Additionally, new front-load models fill out the new high end, while new top-load models fill out the new low end, both in terms of price and energy consumption. The magnitude and significance of these particular price patterns will be discussed in more detail below.

Figure 4 provides a visual description of effects on the menu of products available in the market following the policy changes. In particular, consistent with the third prediction of the oligopolistic price discrimination model, the new standards resulted in an increase in the variety of front-load models offered in the market (shown in the bottom two panels). Interestingly, it is clear that this was not at the expense of model variety - at least in terms of number of models available and purchased - of top-load models (shown in the top two panels). Indeed, the overall number of both front- and top-load models expanded around each standard change. New top-load models tended to replace the lowest efficiency products in both cases. This is evident when looking at the average kWh/year and average price levels for each of the groups in the year preceding and the year following each standard change shown in table 4; new top-load models entering after each standard change are of a similar efficiency and price-point as the TL High EE group now making up the low-end of the market, while new front-load models entering after each standard change are of a similar efficiency (and even higher price-point) compared to the existing front-load models in the market.


2004 Standard Change

2007 Standard Change

Figure 4. Number of Models by Market Segment

Note: This figure shows the number of individual models available in each of the nine market segments defined in table 4, as well as overall, in each month surrounding both the 2004 (left-hand panels) and 2007 (right-hand panels) standard changes.
Source: Author calculations.

Returning to the question of the price effects within each of the defined market segments, I run a series of regressions to quantify the price effects separately for each of these groups. Once again, I use both an estimation strategy that flexibly controls for time effects (equation 8), and a strategy that assumes a linear time trend allowed to change at the standard date (equation 9). In these estimating equations $p_{it,j}$, $Standard_t$, $Trend_t$, τ_t and γ_i are all defined as in equations 7 and 6. Now however, the j subscript is an index over the set of seven market segments defined in table 4 (where models that enter following, or exit prior to, the standard are grouped together for front- and top-load models separately). In the regressions without fixed effects γ_i is omitted. Note that for the two groups "FL Exit/Enter" and "TL Exit/Enter," the individual models do not span the standard change date, so the term $Standard_t$ is omitted for these two groups in the fixed-effect regressions. Additionally, there are no models in the market segments "TL ES" or "TL ES Decert" during the 2004 standard change. Finally, the term $kWh_{it,j}$, which is the FTC annual energy use measure, is included as well in order to capture the efficiency-adjusted change in price.

$$p_{it,j} = \alpha_j + \delta_j Standard_t + \nu_j kWh_{it,j} + \tau_t + \gamma_i + \varepsilon_{it,j} \tag{8}$$

$$\begin{aligned} p_{it,j} = & \alpha_j + \psi_j Trend_t + \delta_j Standard_t + \phi_j Standard_t \cdot Trend_t \\ & + \nu_j kWh_{it,j} + \gamma_i + \varepsilon_{it,j} \end{aligned} \tag{9}$$

The results for each market segment are shown in tables 5, 6 and 7. In all cases columns 1, 2, 5 and 6 show the results using the estimation strategy shown in equation 8, while columns 3, 4, 7, and 8 show the results using the linear time assumption shown in equation 9. Columns 1 through 4 show results for the 2004 standard change, while columns 5 through 8 show results for the 2007 standard change. Columns 1, 3, 5, and 7 omit fixed-effects, but show the efficiency-adjusted average price change by including $kWh_{it,j}$. Finally, columns 2, 4, 6, and 8 control for both model-specific fixed effects and $kWh_{it,j}$. The favored specifications are the those that include model-specific fixed effects.

The results for the front-load categories, making up the top of the market, can be seen in table 5. Panel A of table 5 shows the results for front-load models that span the standard change (FL), while panel B shows the results for the models that exited prior to or entered following the standard change (FL Exit/Enter). The only clear pattern emerging from the front-load models is that within-model prices, particularly following the 2007 standard change, for both pre existing and new models, began trending downward more quickly following the standard effective date relative to before. This pattern was also true for new front-load models following the 2004 standard change, though not for the models spanning the standard change in 2004. While the instantaneous price effect tended to be negative across the board for pre existing front-load models, the effect is only statistically significant in a couple of cases. Front-load models introduced following the standard tended to be more expensive on average than those dropped prior to the standard change, though the difference is never statistically significant.

The results for the middle of the market are shown in table 6. Panel A of table 6 shows the results for top-load models that were ES certified both before and after the standard change (TL ES); panel B shows the results for top-load models that were decertified from ES as a result of the standard change (TL Decert.); and panel C shows the results for top-load models that were not ES qualified, but were not likely to have been eliminated directly be the new standard (TL High EE). The middle of the market is made up of only the TL High EE group in 2004, which experienced within-model drops in price of \$69, significant at a 10 percent confidence level, shown in columns 2 and 4 of panel C in table 6. At the time of the 2007 standard change, the middle of the market is also made up of ES qualifying top-load models, and those decertified from ES by the 2007 standard. Decertified models experienced consistent and significant drops in price of around \$42 within-model, shown in columns 6 and 8 of panel B in table 6. This is consistent with the fact that these products have presumably lost a quality signal they previously had. Products that maintained their ES label across the standard change experienced a large significant drop in price of around \$110 within-model, shown in column 6 of panel A in table 6. This effect is significant even given that there were only ten models in this category, though only in the specification using time fixed effects and not the linear trend assumption. This makes sense, given that there is a clearly nonlinear price pattern for this group prior to the standard change evident in center-right panel of figure 3. This implies that the imposition

Table 5—Heterogeneous Price Effects at New Standard Effective Date (Top of Market)

Dependent variable: Price	2004 Standard Change				2007 Standard Change			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: FL							
Standard	-101.5*	-56.09	-73.59	-23.45	-63.48***	-14.43	-19.58	18.37
	(54.20)	(48.21)	(47.55)	(32.32)	(22.70)	(14.13)	(18.02)	(13.53)
StandardxTrend			-21.65	-1.303			-6.736*	-9.671***
			(12.61)	(8.188)			(3.612)	(2.340)
Trend			4.349	-9.378			-12.02***	-10.76***
			(9.504)	(6.659)			(3.008)	(1.532)
Observations	255	255	255	255	1,374	1,374	1,374	1,374
R-squared	0.165	0.368	0.147	0.330	0.146	0.522	0.143	0.514
Number of models	14	14	14	14	76	76	76	76
	Panel B: FL Exit/Enter							
Standard	54.39		98.95		199.5		137.7	
	(151.8)		(139.4)		(174.7)		(142.7)	
StandardxTrend			-21.46*	-15.53***			-2.534	-18.97*
			(12.12)	(2.028)			(13.01)	(10.10)
Trend			12.03	-1.450**			-0.634	2.581
			(10.07)	(0.644)			(10.79)	(9.189)
R-squared	434		434	434	521		521	521
Observations	0.111		0.103	0.461	0.019		0.013	0.230
Number of models	58		58	58	90		90	90
Model fixed effects	-	Yes	-	Yes	-	Yes	-	Yes
Time fixed effects	Yes	Yes	-	-	Yes	Yes	-	-
Linear time trend	-	-	Yes	Yes	-	-	Yes	Yes
kWh/year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table shows the regression results for the top of the market product categories. The dependent variable in all cases is price deflated using the consumer price index to December 2009 prices. The term "Standard" is a dummy variable equal to zero prior to the standard effective date, and equal to one starting on the standard effective date. The term "Trend" is a linear time trend. Columns 1 through 4 show results for the 2004 standard change, while columns 5 through 8 show results for the 2007 standard change. Columns 1, 3, 5 and 7 include no fixed effects, but show the efficiency-adjusted average price change by including kWh_{it}; finally, columns 2, 4, 6 and 8 control for both model-specific fixed effects and kWh_{it}. Standard errors clustered at the model-number level are shown in the parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

of the linear time trend is too restrictive in the TL ES case. Therefore, columns 5 and 6 are the favored specifications for panel A of table 6.

Finally, price effects for the bottom of the market are shown in table 7. Panel A of table 7 shows the results for inefficient top-load models that span the standard change, but were likely to be eliminated by the new standard (TL Low EE), while panel B shows the results for the top-load models that exited prior to or entered following the standard change (TL Exit/Enter). Within-model prices of the TL Low EE group dropped significantly at the time of the 2004 standard change by between $49 and $58, shown in columns 2 and 4 of panel A in table 7. This may be due in part to discounting obsolete models that no longer meet the standard. The price drop of the TL Low EE group was less consistently significant following the 2007 standard change, though there is some evidence that not only did within-mode prices drop by around $20, but they began trending downward around $6 per month more quickly following the 2007 standard change relative to before, shown in columns 7 and 8 of panel A in table 7. New top-load models were significantly less expensive in efficiency-adjusted terms than those dropped at the time of the new standard by over $200, though this difference is only significant following the 2004 standard effective date, shown in panel B of table 7.

Taking figures 3 and 4, and tables 5, 6 and 7 as a whole, a clear pattern begins to emerge. As the new ME and ES standard becomes more restrictive, the price of models at the low end and mid-low end of the market dropped discontinuously in efficiency-adjusted terms. This was seen for the TL Low EE groups both in 2004 and 2007, the TL High EE group in 2004 and the TL ES group in 2007. Models decertified from ES dropped in price as well, though there are not many of them, and over half exited the market within a year of the standard. New top-load models entering the market tended to replace the low end of the market. While they met the new standard, the majority were not ES qualified, and tended to replace relatively inexpensive, inefficient models, although there was a modest high-end top-load segment maintained. The new top-load models introduced

Table 6—Heterogeneous Price Effects at New Standard Effective Date (Middle of Market)

Dependent variable: Price	2004 Standard Change				2007 Standard Change			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: TL ES							
Standard					-104.1*	-109.2*	-16.71	-1.794
					(53.65)	(53.29)	(21.93)	(40.91)
StandardxTrend							4.539	12.77*
							(9.104)	(6.766)
Trend							-11.15*	-19.82***
							(5.835)	(5.138)
Observations					185	185	185	185
R-squared					0.734	0.626	0.717	0.535
Number of models					10	10	10	10
	Panel B: TL Decert.							
Standard					-52.09**	-42.10*	-43.91**	-42.15**
					(20.34)	(21.92)	(18.01)	(15.15)
StandardxTrend							4.310	-0.153
							(4.791)	(4.810)
Trend							-7.024**	-8.289***
							(2.696)	(1.955)
R-squared					297	297	297	297
Observations					0.421	0.498	0.412	0.470
Number of models					17	17	17	17
	Panel C: TL High EE							
Standard	-66.27	-68.75*	-53.66	-68.96*	27.28*	3.631	36.66**	8.069
	(131.1)	(37.10)	(122.8)	(35.46)	(15.10)	(5.774)	(16.13)	(6.315)
StandardxTrend			0.457	4.877			-1.572	-8.593***
			(11.37)	(6.037)			(3.461)	(2.616)
Trend			-9.503	-4.256			-6.940**	-2.724***
			(12.77)	(5.151)			(2.777)	(0.774)
R-squared	228	228	228	228	865	865	865	865
Observations	0.228	0.226	0.221	0.185	0.081	0.293	0.078	0.287
Number of models	14	14	14	14	54	54	54	54
Model fixed effects	-	Yes	-	Yes	-	Yes	-	Yes
Time fixed effects	Yes	Yes	-	-	Yes	Yes	-	-
Linear time trend	-	-	Yes	Yes	-	-	Yes	Yes
kWh/year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table shows the regression results for the middle of the market product categories. The dependent variable in all cases is price deflated using the consumer price index to December 2009 prices. The term "Standard" is a dummy variable equal to zero prior to the standard effective date, and equal to one starting on the standard effective date. The term "Trend" is a linear time trend. Columns 1 through 4 show results for the 2004 standard change, while columns 5 through 8 show results for the 2007 standard change. Columns 1, 3, 5 and 7 include no fixed effects, but show the efficiency-adjusted average price change by including kWh_{it}; finally, columns 2, 4, 6 and 8 control for both model-specific fixed effects and kWh_{it}. There were no models in the "TL ES" or the "TL Decert." categories at the time of the 2004 standard change. Standard errors clustered at the model-number level are shown in the parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 7—Heterogeneous Price Effects at New Standard Effective Date (Bottom of Market)

Dependent variable: Price	2004 Standard Change				2007 Standard Change			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: TL Low EE							
Standard	-34.92	-48.92***	-60.18*	-57.71***	-18.40	-21.16	-21.43*	-19.31*
	(25.10)	(15.81)	(32.65)	(15.51)	(13.94)	(12.60)	(12.58)	(10.60)
StandardxTrend			-3.150	-0.674			-6.135**	-5.357*
			(4.869)	(1.750)			(2.450)	(2.809)
Trend			-2.326	-5.584***			-0.385	-0.611
			(3.162)	(1.003)			(0.785)	(0.755)
Observations	500	500	500	500	538	538	538	538
R-squared	0.062	0.517	0.040	0.485	0.094	0.300	0.070	0.216
Number of models	35	35	35	35	37	37	37	37
	Panel B: TL Exit/Enter							
Standard	-202.0**		-202.0**		-210.5		-220.5	
	(83.62)		(81.90)		(216.0)		(200.3)	
StandardxTrend			-7.275**	-2.824***			-3.931	2.972
			(3.168)	(1.000)			(10.76)	(3.245)
Trend			-3.627	-2.342***			2.967	-6.436**
			(2.613)	(0.621)			(9.553)	(3.125)
R-squared	1,656		1,656	1,656	713		713	713
Observations	0.213		0.211	0.152	0.230		0.223	0.099
Number of models	212		212	212	118		118	118
Model fixed effects	-	Yes	-	Yes	-	Yes	-	Yes
Time fixed effects	Yes	Yes	-	-	Yes	Yes	-	-
Linear time trend	-	-	Yes	Yes	-	-	Yes	Yes
kWh/year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table shows the regression results for the bottom of the market product categories. The dependent variable in all cases is price deflated using the consumer price index to December 2009 prices. The term "Standard" is a dummy variable equal to zero prior to the standard effective date, and equal to one starting on the standard effective date. The term "Trend" is a linear time trend. Columns 1 through 4 show results for the 2004 standard change, while columns 5 through 8 show results for the 2007 standard change. Columns 1, 3, 5 and 7 include no fixed effects, but show the efficiency-adjusted average price change by including kWh_{it}; finally, columns 2, 4, 6 and 8 control for both model-specific fixed effects and kWh_{it}. Standard errors clustered at the model-number level are shown in the parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

after the 2004 standard also tended to experience a significant large-magnitude price drop, in efficiency-adjusted terms, compared to those they replace, and their prices tended to trend downward more quickly following the standard relative to the price trend of those models that exited the market prior to the standard. These effects are of similar magnitude concurrent with the 2007 standard, though not statistically significant. At the high end of the market, new front-load models appear to be designed to expand efficiency available in the market upward, in that close to 100 percent of front-load models introduced following the standard changes were ES qualified. They did tend to be more expensive on average than those they replaced, though not statistically significantly so. However, the prices of new front-load models dropped more quickly over time than the prices of those they replaced. Additionally, there is some evidence that the within-model prices of front-load models that remained in the market across the standard trended downward more quickly following the standard relative to before, particularly in 2007.

VI. Conclusion

In this paper I corroborate evidence found by Chen, Dale and Roberts (2013) that prices of clothes washers dropped on average at the time the ME and ES standard restrictions came into effect in 2007, and showed that this pattern was even more pronounced at the time these standards were restricted in 2004. I outline the classic Mussa and Rosen (1978) model of second-degree price discrimination, and extend previous discussions of the predictions in this model of imposing a more restrictive ME standard by discussing the implications of simultaneously changing the ES labeling standard as well. Using this model, I derive three primary predictions of the effect of a more restrictive ME and ES standard in the imperfectly competitive model that are in contrast to the predictions implied by a perfectly competitive model: First, (i) the imposition of a ME standard in a perfectly competitive market would predict an increase in the price of products in the market, particularly low-end products that are close substitutes to products eliminated by the standard. On the other hand, in a market in which firms have been engaging in second-degree price discrimination, the imposition of a more stringent ME standard would impose downward pressure on prices across the market, particularly at the mid- to low-end. Second, (ii) the predicted effect of a simultaneous change in both the ME and ES standards on the price of products that remain ES certified, or are front-load models, is ambiguous in the imperfectly competitive market. However, an observed drop in these prices would be consistent with price discrimination. Finally, (iii) in an oligopolistic market, the imposition of a ME standard could stimulate expansion upward in the levels of efficiency supplied to the market, and potentially increase the general diversity of products available in the market in other dimensions as well. This would not necessarily be the case in a perfectly competitive setting.

I have shown evidence consistent with price discrimination on all three of these points. The results from testing the first two predictions are summarized in figure 5. With regard to point (i), I have shown that as the new ME and ES standards became more restrictive, the price of models at the low-end and mid-low end of the market (the TL Low EE groups both in 2004 and 2007 and the TL High EE group in 2004) dropped discontinuously, particularly in efficiency-adjusted terms. Additionally, new top-load models entering the market replaced the low end of the market, were not in large part ES qualified, and tended to be significantly less expensive, in efficiency-adjusted terms, compared to those they replaced, particularly following the 2004 standard. With regard to the second point (ii), the TL ES group experienced a statistically significant price drop at the time of the 2007 standard change. Finally, with regard to point (iii), at the high end of the market new front-load models extended efficiency of products available in the market upward; close to 100 percent of front-load models introduced following the standard changes were ES qualified, compared to only around 15 percent of new top-load models. Additionally, the overall number of individual models available in the market increased. This was especially true for front-load models, but was true for top-load models as well.

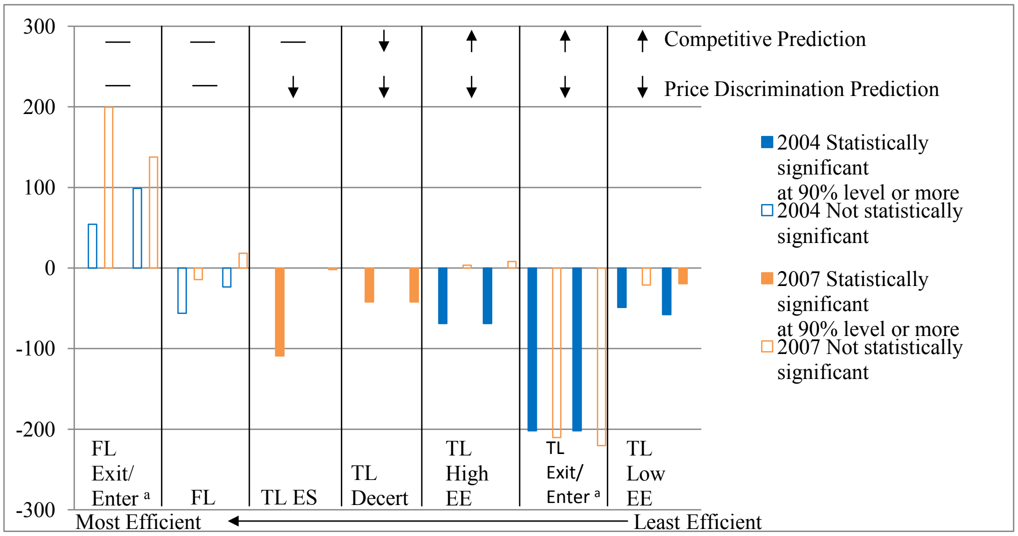


Figure 5. Price Results Summary

Note: This figure depicts the point-estimates of the $T \cdot Standard$ coefficients from the fixed-effect regression results (columns 2 and 4 for 2004, and 6 and 8 for 2007, in order left to right) of the effect of the 2004 and 2007 standard changes on prices from tables 5, 6 and 7. The solid bars represent point estimates that were significant at the 90% confidence level or higher, while the outlined bars represent point estimates that were not statistically significant. The rows of arrows at the top depict the model predictions for the price effects in each of these market segments in the case of either perfect competition, or second-degree price discrimination.

[a] The coefficients for the FL Exit/Enter and TL Exit/Enter groups are from the regressions with no fixed-effects (columns 1, 3, 5 and, 7 in the regression tables).

Source: Author calculations.

This paper demonstrates evidence consistent with price discrimination in the US clothes washer market: concurrent with the effective dates of both the 2004 and 2007 standard changes, the pattern of the drop in prices across various efficiency-related market segments, as well as patterns of change in the menu of products offered, are consistent with those predicted by the second-degree price discrimination model, and not readily consistent with a perfectly competitive market. The implication for these results is that, in addition to negative environmental externalities, energy efficiency regulation directly addresses an additional market failure – namely, market power and the resulting under-provision and over-charging for energy efficiency relative to the social optimum. To-date there has been almost no discussion of the implication of the oligopolistic structure of the supply side of the market in the policy implementation of ME appliance standards. Results from this study suggest that such a discussion may be warranted.

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Appendix A: Retailers in NPD Data

Retailers in NPD data:

BJs Wholesale Club
Bloomingdales
Boscovs
Circuit City
Dillard’s
Fortunoff
Fred Meyer
Gottschalks
HH Gregg
JC Penney
Meijer
Nebraska Furniture Mart
PC Richard & Sons
Pamida
RC Willey
Sears
Shopko
Target
Ultimate Electronics

”Projected” sales [a] included for:

Home Depot
Menards
Navy Exchange
Queen City Appliance
REX Stores
Vanns

[a] Projected refers to the fact that NPD included estimates of sales for this subset of retailers in their data. They claim that the share of overall market sales was no greater that 5% for all projected retailers combined for a given time period.