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Appliance Efficiency Standards and Price Discrimination

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Abstract

I explore the effects of two simultaneous changes in minimum energy efficiency and ENERGY STAR standards for clothes washers. Adapting the Mussa and Rosen (1978) and Ronnen (1991) second-degree price discrimination model, I demonstrate that clothes washer prices and menus adjusted to the new standards in patterns consistent with a market in which firms had been price discriminating. In particular, I show evidence of discontinuous price drops at the time the standards were imposed, driven largely by mid-low efficiency segments of the market. The price discrimination model predicts this result. On the other hand, in a perfectly competition market, prices should increase for these market segments. Additionally, new models proliferated in the highest efficiency market segment following the standard changes. Finally, I show that firms appeared to use different adaptation strategies at the two instances of the standards changing.

Minimum efficiency standards for household appliances address several market failures including environmental externalities, information asymmetries, principal-agent problems, consumer biases, and imperfect competition. Chen, Dale and Roberts (2013) found a 2007 restriction in efficiency standards for clothes washers corresponded with dropping clothes washer prices on average. While they mention imperfect competition as one possible explanation for this phenomenon, they put aside the question of market structure and while assuming prices dropped as a result of economies of scale in production, go on to estimate consumer welfare benefits of the standard change. I return to the question of market structure and directly test whether imperfect competition explains these price drops.

The markets for large energy consuming appliances are likely oligopolistic or monopolistically competitive, rather than perfectly competitive. Market shares for many energy consuming durables are increasingly controlled by a shrinking handful of manufacturers. For

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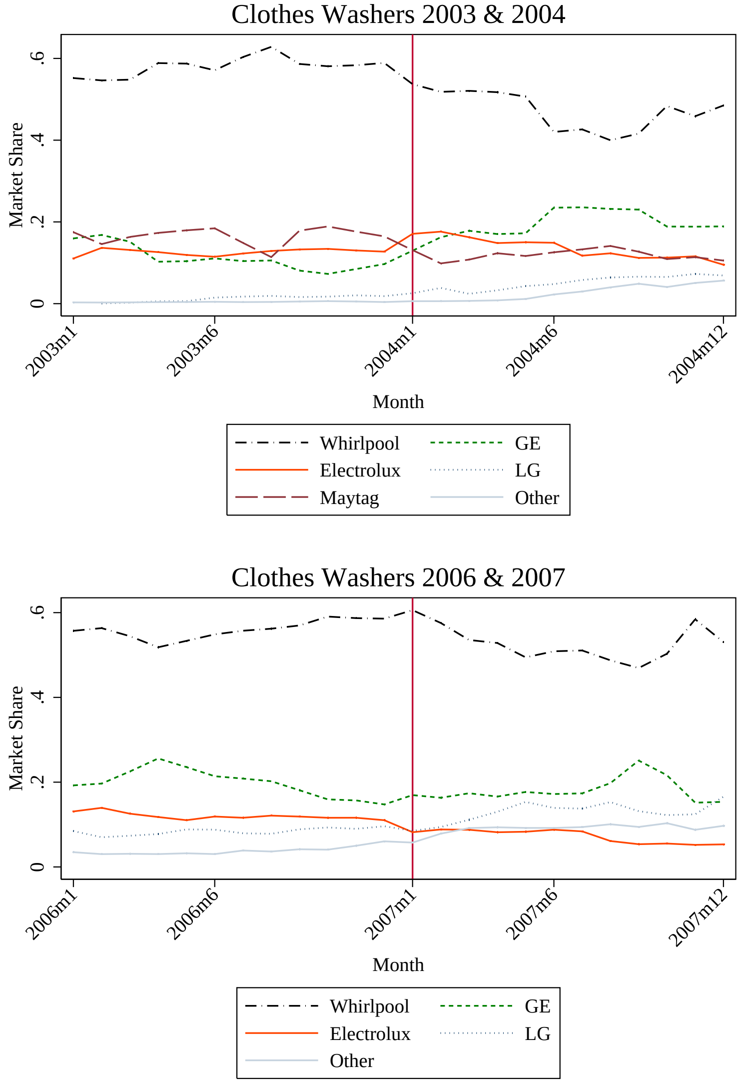
clothes washers – the focus of this paper – these manufacturers are primarily Whirlpool, Electrolux, GE, and increasingly LG. Whirlpool merged with Maytag in 2006, and Ashenfelter, Hosken and Weinberg (2011) show that the result was an increase in price and decrease in product variety for some appliances, an outcome consistent with consolidating market power. Indeed, in data used for this paper Whirlpool – including its subsidiary brands – controlled close to 60% of the clothes washer market. Figure 1 shows the market shares of the largest manufacturers during my study period. Even given this level of consolidation, it is difficult to demonstrate that firms are exercising market power in pricing using only market equilibrium prices and quantities.

I demonstrate that market responses to increasingly stringent standards were more consistent with a market made up of price discriminating producers, as opposed to a perfectly competitive market. I use point-of-sale (POS) data for clothes washers spanning two changes to minimum efficiency standards, one on January 1st, 2004 and one on January 1st, 2007. ENERGY STAR standards changed at each of these dates as well. I show that clothes washer prices experienced both an immediate level drop, as well as a downward break in trend, at the effective dates of both new standards. In particular, the prices of mid-low efficiency products showed the largest immediate level drop – a pattern consistent with price discrimination. In a perfectly competitive market, in contrast, prices of mid-low efficiency models should increase following a tightening standard. The downward trend-break tended to be larger in magnitude for higher efficiency models. Additionally, I demonstrate that the new standards were associated with increased model proliferation within the highest efficiency categories. Finally, I show that firms apparently used different strategies to respond to these two changes in standards: at the 2004 standard change, many existing models were modified and reintroduced into the market, indicating possible "low-hanging fruit" in terms of inexpensive efficiency improvements. This revamping of existing stock did not appear as prevalent in 2007.

This paper will proceed as follows: Section 1 outlines the history of relevant minimum and ENERGY STAR standard changes; Section 2 outlines the model and derives testable predictions; Section 3 describes the data; Section 4 describes the estimation strategy and presents the results of the analysis, and Section 5 concludes.

Figure 1: Market Share by Manufacturer in Study Period



Note: Market share as measured in the NPD data of the largest manufacturers in the time periods just around the standard change dates for clothes washers. The four largest manufacturers of clothes washers are Whirlpool, GE, Electrolux, and increasingly LG. Maytag was a major manufacturer prior to 2006, at which point they merged with Whirlpool. The depicted market share for Whirlpool includes all its subsidiary brands appearing in the NPD data (Estate, Inglis, Roper and KitchenAid, as well as Maytag and its subsidiary brands Amana and Magic Chef after 2006). GE's market share includes sales by its subsidiary brands (Hotpoint and Ariston). Electrolux's market share includes sales by its subsidiary brands (Frigidaire, Westinghouse and White Westinghouse). All other manufacturers represented in the data are aggregated into the "Other" category (Electro Brand, Equator Appliances, Eurotec, Fagor, Fisher & Paykel, Haier, Koblenz, Miele, Samsung, Speed Queen, and Summit).

1 Minimum Energy Efficiency and ENERGY STAR Standards

In 1975 the Energy Policy and Conservation Act (EPCA) was enacted laying the initial groundwork at the national level for a variety of energy efficiency measures including test procedures, labels and targets, and was amended in 1979 to include energy efficiency standards to be established by DOE. In 1987 the National Appliance Energy Conservation Act (NAECA) established legislation stipulating that minimum efficiency for a variety of appliances manufactured for sale in the United States undergo periodic restriction. Further legislation, including the Energy Policy Act (EPAct) of 1992, as well as EPAct 2005, and Energy Independence and Security Act (EISA) of 2007 have continued to extend the number of products subject to standards, as well as updated standards, test procedures, and review schedules.

Clothes washers were among the initial set of products for which minimum efficiency standards were established through NAECA; in 1987 Congress adopted the first federal standard for clothes washers to be effective in 1988. The 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 the DOE adopted 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 a labeling standard by ENERGY STAR. This is not a restrictive standard, but rather establishes a benchmark of efficiency such that products exceeding that benchmark qualify for the ENERGY STAR label, signaling a model as highly efficient to potential customers.

Table 1 provides a breakdown of the minimum and ENERGY STAR standards for clothes washers enacted between 1991 and 2007. Before 2004, the minimum 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 minimum standard became based on the Modified Energy Factor (MEF). The MEF, also measured in cubic feet per kWh per cycle, added to the EF by incorporating the energy required to dry moisture remaining in the clothing following the final spin cycle. On January 1st, 2004, the clothes washer standard changed, requiring that the MEF be no less than 0.65 for compact models, and 1.04 for standard-class (both top-an front-load) models. Simultaneously the ENERGY STAR standard (only established for standard-class models) restricted the minimum MEF cut-off ENERGY STAR qualification from 1.26 to 1.42. Then, on January 1st, 2007, the minimum standard was further restricted for standard-class top- and front-load models, requiring the MEF be no less than 1.26. The ENERGY STAR standard also increased on January 1st, 2007, requiring the MEF be no less than 1.72, and now also requiring these models have a Water Factor (WF) of no more than 8.0. The WF is the number of gallons per cycle per cubic foot used by the washer.

Table 1: Clothes Washer Minimum and ENERGY STAR Standards between 1991 and 2007

Adopted Date	Effective Date	Minimum Efficiency Requirement			ENERGY STAR Requirement
		Compact Top Load	Standard Top Load	Front Load	
1991	1994	EF$\geq$0.9	EF$\geq$1.18	-	-
2001	2001	-	-	-	MEF$\geq$1.26
2001	2004	MEF$\geq$0.65	MEF$\geq$1.04	MEF$\geq$1.04	MEF$\geq$1.42
2001	2007	(no change)	MEF$\geq$1.26	MEF$\geq$1.26	MEF$\geq$1.72 & WF$\leq$8.0

Note: As of 1994 the minimum standard was based on the Energy Factor (EF) which measures overall washer efficiency in terms of cubic feet per kWh per cycle. As of 2004 the minimum standard became based on the Modified Energy Factor (MEF) which is also measured in cubic feet per kWh per cycle, but takes into account not only the machine electrical energy and water heating energy, but also the energy required for moisture removal, whereas the EF did not account for this additional drying energy. Starting in 2007, the ENERGY STAR criteria also included a requirement based on the Water Factor (WF) which is the number of gallons per cubic foot per cycle that the clothes washer uses. Compact models are models less than 1.6 cubic feet and standard-class models are larger than 1.6 cubic feet. During this time there was no ENERGY STAR criteria for compact models, only standard-class models.

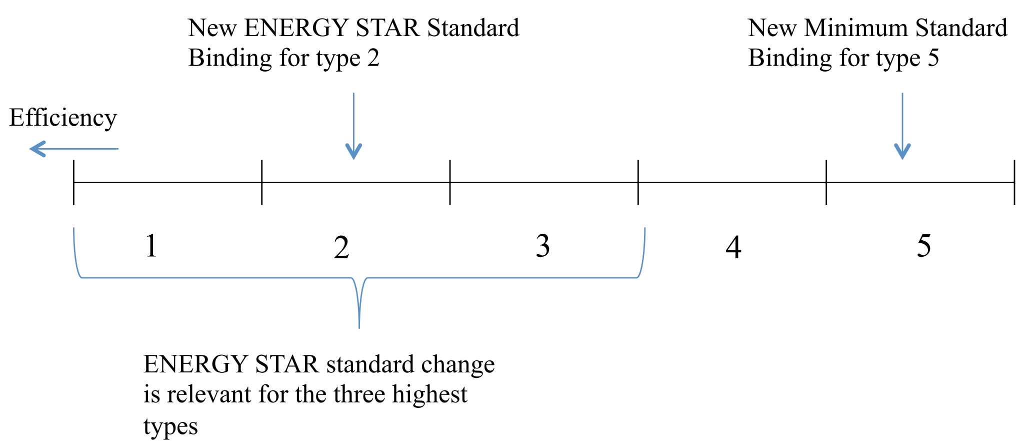
2 Model of Consumer Durables and Market Power

In this section I present and extend a classic model of second-degree price discrimination for a quality-differentiated set of durable goods. I extend the model slightly to fit the setting of a simultaneous change in the minimum and ENERGY STAR standards of clothes washers. The model provides predictions about how the standard changes should affect the market prices and innovation patterns of clothes washers in a market with price discrimination as compared to perfect competition.

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, which induces consumers to sort themselves into purchasing the product that targets their willingness to pay level. 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. Most papers that discuss this model simplify by using two consumer types. I assume five consumer types – summarized in Figure 2 – because when both the minimum and ENERGY STAR standards change simultaneously in my setting, there will be dynamic changes across the market efficiency spectrum in a slightly more complicated way than can be approximated with two consumer types.

I define the consumer preference heterogeneity by assuming five consumer types, where type 1 has the highest valuation for efficiency, and type 5 has the lowest. The market will therefore consist of five efficiency segments corresponding to the five consumer types. Assume the ENERGY STAR standard will only impact the highest efficiency market segments, here consisting of types 1, 2 and 3.[1] Assume segment 1 consists of all products that are ENERGY STAR certified both before and after the new standard; segment 2 consists of all products that were ENERGY STAR certified but are decertified as a result of the new ENERGY STAR standard, and segment 3 consists of high-end products that are never ENERGY STAR certified, but are the closest substitutes to the newly decertified segment 2 products. Then, at the lower end of the market, assume segment 5 consists of models that will be directly affected by a tightened minimum efficiency standard, and segment 4 are mid-low end products that are the closest substitutes to the directly affected segment 5 products. These market segments are depicted in Figure 2.

Figure 2: Definition of Energy Efficiency-Based Market Segments/Consumer Types



Note: Definition of the market segments/consumer types in terms of energy efficiency categorizations used in this model. Each efficiency category/market segment will correspond with a consumer "type" based on that type's preferences for efficiency. Consumers of type 5 have the lowest willingness to pay for energy efficiency while consumers of type 1 have the highest willingness to pay for efficiency. A change in the ENERGY STAR standard is assumed to directly affect market segment/consumer type 2. A change in the minimum standard is assumed to be binding for market segment/consumer type 5.

In the following sections I outline the model and derive testable predictions: in Section 2.1 I present the basic model of a price discriminating monopolist facing these five consumer types and outline the predictions of how a minimum standard change alone will affect prices; in Section 2.2 I extend the model and outline the predictions of how a change in the ENERGY STARt standard alone will affect prices; in Section 2.3 I discuss the implication of the market

[1]Note that it is likely that this heterogeneity among the highest type of the consumers is relevant; the Consortium for Energy Efficiency (CEE) rates appliances that are all ENERGY STAR qualified into three additional energy efficiency tiers. These higher efficiency tiers often indicate the level of future ENERGY STAR standards. Also, some have suggested that consumers tend to be more brand-conscious at the high efficiency end of the spectrum of the market (Katz, 1984). It therefore stands to reason that those consumers might also be more conscious of small variation in other important model characteristics as well, such as energy efficiency.

being oligopolistic or monopolistically competitive, rather than monopolistic; in Section 2.4 I outline the testable predictions from the model to show the effect on prices of a simultaneous change in both the minimum and ENERGY STAR standards by combining the predictions from Sections 2.1 and 2.2, and finally in Section 2.5 I discuss two other testable predictions of a minimum standard change in this model.

2.1 Monopoly Price Discrimination and Minimum Standard Change

I present here a simple reproduction, with five 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).[2] I then outline, following Fischer (2005), the result of imposing a minimum standard in this model.

Assume consumers have unit demand for a good, here an energy consuming durable such as a clothes washer. This means that each consumer will purchase at most one unit of the good. Assume five types of consumers – high (type 1) to low (type 5)– characterized by having different willingness to pay for efficiency; assume θ^k is the valuation of consumer type k for efficiency e where, without loss of generality, $\theta^5 < \theta^4 < \theta^3 < \theta^2 < \theta^1$. In equilibrium there will be five models of clothes washers provided by the market, indexed by j, which vary over efficiency level (e_j) and price (p_j). Utility of consumer k for model j is:

$$
\begin{aligned}
U_{kj} &= \theta^k e_j - p_j \\
&\text{where:} \\
\theta^k \in \{\theta^5, \theta^4, \theta^3, \theta^2, \theta^1\} &= \text{valuation of energy efficiency } e \text{ of the three consumer types} \\
e_j &= \text{energy efficiency level of model } j \\
p_j &= \text{purchase price of model } j
\end{aligned}
$$

Suppose there are N consumers and $s_k N$ have valuation θ^k, where $\sum_{k=1}^{5} s_k = 1$. 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 $c(e_j)$, and that $c(e_j) \geq 0$, $c'(e_j) \geq 0$ and $c''(e_j) > 0$.[3] 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.

Before looking at the monopoly case, I first show what the social welfare maximizing/perfectly competitive price and efficiency schedule would be in this simple model. A social planner would choose the efficiency levels to maximize total welfare. They would therefore solve the optimization problem presented in Equation 1.

[2] A more step-by-step derivation of the model for three consumer types, which is easily extended to any discrete number of types, is provided in Appendix 1.

[3] The choice of a strictly convex cost of quality (or alternatively a concave-in-quality objective function of the firm through some other input to profit) is a necessary condition for a separating price discrimination equilibrium to be optimal for the monopolist (Salant, 1989).

$$\max_{e_1,e_2,e_3,e_4,e_5} W = \sum_{j=1}^{5} s_j \cdot \left(\theta^j e_j - c\left(e_j\right)\right) \tag{1}$$

The first order conditions for the social planner are shown in Equation 2.

$$c'\left(e_j^*\right) = \theta^j,\ \forall j \in \{1,2,3,4,5\} \tag{2}$$

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. While consumer demand is perfectly inelastic, in a perfectly competitive setting with free entry of new firms, price above marginal cost would result in excess supply. Therefore the optimal prices are also equal to marginal cost. This result is shown in Equation 3.

$$c'\left(e_j^*\right) = p_j^*,\ \forall j \in \{1,2,3,4,5\} \tag{3}$$

Now I turn to the monopoly case. The monopolist picks the levels of efficiency and price (e_j, p_j) for each of its five models in order to maximize profit. They want to impose a price-efficiency schedule that will extract the maximum consumer surplus from all five types of consumer. If the monopolist could perfectly price discriminate, they would price so as to extract all consumer surplus. Therefore they would have an incentive to provide the social welfare maximizing level of efficiency $c'\left(e_j^{PD}\right) = \theta^j,\ \forall j \in \{1,2,3,4,5\}$, where e_j^{PD} is the monopoly's optimal choice of energy efficiency to sell to consumer type j if they could perfectly price discriminate. In order to extract all the consumer surplus, they would set price just such that each consumer's utility is equal to zero, meaning that consumers would just be indifferent between purchasing and not purchasing the product. However, if the monopolist cannot identify which consumer is which, and they simply provide an efficiency-price schedule consisting of the socially optimal levels of efficiency sold at prices such that $U^j = \theta^j e_j^{PD} - p_j = 0$ for each level of $e_j^{PD},\ \forall j \in \{1,2,3,4,5\}$, the outcome would not be an equilibrium. This is because, for example, the type 4 consumer will not follow through on purchasing the type 4 product, but would rather choose to purchase the lowest type product; if the type 4 consumer purchases the type 4 product, they will have utility equal to zero, but if they purchase the lowest type model they will have utility greater than zero. Therefore, the monopolist will not actually succeed in achieving their maximum profit using this strategy.

In the case where the monopolist cannot identify which type of consumer is which, they can't perfectly discriminate, but rather will engage in imperfect – or second-degree – price discrimination. In order to do this they will maximize their profit subject to two sets of constraints. The first set, the Individual Rationality (IR) constraints, guarantee that all five types of consumers are willing to purchase a product at all.[4] The second set of constraints

[4]There could also be a case where the monopolist would find it more profitable to only sell to a subset of consumer types in which case we would not require that the IR constraint for all types hold. For the time being I assume away this case and assume the valuations of all consumer types and production costs are such that the monopolist finds it profitable to serve all consumer types.

are the Incentive Compatibility (IC) constraints, also known as the self-selection constraints. These constraints guarantee that each type is only willing to purchase the model type intended for them, and not the model type intended for any of the other types of consumers. Therefore, the monopolist chooses the efficiency levels and prices of the five types of models they supply by maximizing their profit subject to the IRj and ICj_k constraints, where IRj refers to the IR constraint for the type j consumer, and ICj_k refers to the IC 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 $\theta^1 > \theta^2 > ... > \theta^5$ implies that $IR5$, $IC1_2$, $IC2_3$, $IC3_4$ and $IC4_5$ are binding while all other IR and IC constraints are non-binding.[5] Therefore the monopolist's problem simplifies to the that in Equation 4.

$$\begin{aligned}\max_{p_1,p_2,\ldots,p_5,e_1,e_2,\ldots,e_5} \pi = \sum_{j=1}^{5} s_j \cdot (p_j - c(e_j)) \qquad (4)\\ s.t.\\ IR5: \theta^5 e_5 - p_5 = 0\\ ICj_{j+1}: \theta^j e_j - p_j = \theta^j e_{j+1} - p_{j+1}, \forall j \in \{1,2,3,4\}\end{aligned}$$

The solution for the monopolist under second-degree price discrimination $(\bar{e}_j, \bar{p}_j)$, $\forall j \in \{1,2,3,4,5\}$, is presented in Equation System 5.

$$\begin{aligned}c'(\bar{e}_j) &= \theta^j - \frac{\sum_{k=1}^{j-1} s_k}{s_j}\left(\theta^{j-1} - \theta^j\right), \ \forall j \in \{2,3,4,5\} \qquad (5)\\ c'(\bar{e}_1) &= \theta^1\\ \bar{p}_5 &= \theta^5 \bar{e}_5\\ \bar{p}_j &= \bar{p}_{j+1} + \theta^j(\bar{e}_j - \bar{e}_{j+1}), \ \forall j \in \{1,2,3,4\}\end{aligned}$$

These results, consistent with Mussa and Rosen (1978), indicate that the second-degree price discriminating monopolist distorts downward the efficiency of all but the highest type product relative the social welfare maximizing case ($\bar{e}_j < e_j^*$, $\forall j \in \{2,3,4,5\}$). The degree to which the efficiency is distorted downward reflects the trade-off to the monopolist of the profit impact of cutting costs on efficiency, and the risk of the customers substituting downward to lower efficiency products. On the other hand they provide the optimal level of efficiency to the high type ($\bar{e}_1 = e_1^*$). At the same time they charge more for all models than in the welfare maximizing case ($\bar{p}_j > p_j^*$, $\forall j \in \{1,2,3,4,5\}$). This price differential is higher for higher levels of efficiency.

I now turn to a scenario in which a minimum efficiency standard is imposed. This reproduces the same result as others who have discussed minimum efficiency standards in a market facing this type of price discrimination (e.g. Fischer, 2005). Assume in this simple example that the minimum efficiency standard requires that the monopolist only produce models with efficiency level greater than or equal to the socially optimal efficiency level for the

[5] I provide the proof of this for the three type case, which can easily be extended to more types, in Appendix 2.

lowest type of consumer (i.e. the minimum standard requires that $e_j \geq e_5^* \, \forall j \in \{1,2,3,4,5\}$). Note that this is a binding constraint for the monopolist, as absent any policy change, they would be choosing to produce the lowest type model with efficiency level $\bar{e}_5 < e_5^*$. For simplicity I assume the standard is non-binding for all other efficiency levels such that $\bar{e}_j > e_5^*, \, \forall j \in \{1,2,3,4\}$. What happens to the monopolist's price strategy in the short run given the imposition of this standard? To answer this question I re-solve the monopolist's problem after introducing the constraint imposed by the standard, which we know will be binding for the lowest type of model. This new problem is presented in Equation 6.

$$\begin{aligned} \max_{p_1,p_2,\dots,p_5,e_1,e_2,\dots,e_5} \pi = \sum_{j=1}^{5} s_j \cdot (p_j - c(e_j)) \\ s.t. \\ IR5: \theta^5 e_5 - p_5 = 0 \\ ICj_{j+1}: \theta^j e_j - p_j = \theta^j e_{j+1} - p_{j+1}, \forall j \in \{1,2,3,4\} \\ Standard: e_5 = e_5^* \end{aligned} \tag{6}$$

The new monopoly solution of optimal price and efficiency levels given the standard, presented in slightly more detail than before, is shown in Equation System 7.

$$\begin{aligned} c'(e_5^S) &= c'(e_5^*) = \theta^5 \\ c'\left(e_j^S\right) &= \theta^j - \frac{\sum_{k=1}^{j-1} s_k}{s_j}\left(\theta^{j-1} - \theta^j\right), \ \forall j \in \{2,3,4\} \\ c'(e_1^S) &= \theta^1 \\ p_5^S &= \theta^5 e_5^* \\ p_4^S &= \theta^5 e_5^* + \theta^4\left(e_4^S - e_5^*\right) \\ p_3^S &= \theta^5 e_5^* + \theta^4\left(e_4^S - e_5^*\right) + \theta^3\left(e_3^S - e_4^S\right) \\ p_2^S &= \theta^5 e_5^* + \theta^4\left(e_4^S - e_5^*\right) + \theta^3\left(e_3^S - e_4^S\right) + \theta^2\left(e_2^S - e_3^S\right) \\ p_1^S &= \theta^5 e_5^* + \theta^4\left(e_4^S - e_5^*\right) + \theta^3\left(e_3^S - e_4^S\right) + \theta^2\left(e_2^S - e_3^S\right) + \theta^1\left(e_1^S - e_2^S\right) \end{aligned} \tag{7}$$

The result is that $\frac{\partial e_5}{\partial Standard} > 0$, $\frac{\partial e_j}{\partial Standard} = 0, \ \forall j \in \{1,2,3,4\}$, $\frac{\partial p_5}{\partial Standard} > 0$, and $\frac{\partial p_j}{\partial Standard} < 0, \ \forall j \in \{1,2,3,4\}$ (note that this is because $\frac{\partial p_j}{\partial e_5} = (\theta_5 - \theta_4) < 0, \ \forall j \in \{1,2,3,4\}$). Now the lowest and highest types of customers are receiving the socially optimal level of efficiency given their preferences, while the middle types still have a lower level of efficiency relative to the socially optimal level. Although the low-type customer faces a price increase, it is just offset by the increase in their utility from improved efficiency, so they are no worse off from a utility perspective. 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. Imposing a binding standard in that case would then be forcing the lowest efficiency level higher than the socially optimal level, $e_j \geq e^{standard} > e_5^*,\ \forall j \in \{1,2,3,4,5\}$. Therefore, if the market were perfectly competitive, and already operating at the optimal efficiency level, imposing a binding standard would result in $\frac{\partial p_5}{\partial Standard} > 0$ and $\frac{\partial p_j}{\partial Standard} = 0,\ \forall j \in \{1,2,3,4\}$. However, if the increase in price of the lowest efficiency group resulted in type 5 consumers substituting to higher efficiency levels, then one might expect to see $\frac{\partial p_4}{\partial Standard} > 0$ as well.

2.2 ENERGY STAR Standard Change

Here I extend the basic model to explore the implications of a change in only the ENERGY STAR standard in the model with quality differentiated products. Houde (2012) explores the result of an increase in the ENERGY STAR standard for refrigerators in 2008. Pulling somewhat from Houde (2012), assume 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 ENERGY STAR status of the product, etc. Therefore, a change in the ENERGY STAR status of a product, even if the actual energy efficiency does not change, may result in consumers perceiving a change in the efficiency (e_j) of the product j.

Recall I assume a change in the ENERGY STAR standard will only directly affect the three highest efficiency segment of the market, segments 1, 2 and 3. Look first at the case of products decertified from ENERGY STAR as a result of the standard (segment 2). These products may be perceived as less energy efficient now that they no longer have the ENERGY STAR label, even if the actual energy efficiency levels of the products have not changed, so consumers perceive e_2 going down. In the monopoly pricing strategy $\frac{\partial p_2}{\partial e_2} > 0$, therefore a decrease in e_2 will result in a price drop of decertified products in an imperfectly competitive market. In a perfectly competitive market a decertification from ENERGY STAR might result in a negative demand shock, resulting in a drop in the price of segment 2 products as well.

Second, think about products that were not ENERGY STAR certified either before or after the new standard, but are close substitutes to the segment 2 products (segment 3). These products now compete directly with products that were previously ENERGY STAR certified, are of a higher average efficiency, and whose prices, while having just dropped, are likely still higher than p_3. These products are now closer substitutes with more expensive products, which means their prices may go up. However, they are of a lower average efficiency than products that are now closer substitutes and whose prices are dropping. This could mean type 3 consumers could substitute away from them, causing a negative demand shock and resulting in a drop in their price. Therefore, the prediction of the price impact to type 3 products is ambiguous, in either the imperfect competition or perfectly competitive case.

Finally, look at products that qualified for ENERGY STAR both before and after the new standard (segment 1). You might think of two things happening to the type 1 products: first, consumers may perceive decertified products (segment 2) as less energy efficient than before, implying that consumers perceive e_2 decreasing; second, simultaneously the pool of products qualifying for ENERGY STAR now consist of higher efficiency products on average. This means that consumers may perceive e_1 increasing. Therefore, the projected impact on the average price of this class of products is positive in the price-discrimination model, because $\frac{\partial p_1}{\partial e_1} > 0$ while $\frac{\partial p_1}{\partial e_2} < 0$. On the other hand, there is no expected direct effect on type 1 prices in the perfectly competitive model.

2.3 Oligopoly or Monopolistic Competition

In the previous two sections I outlined the price effect of either the minimum or the ENERGY STAR standard changing in a monopolistic market. However, the clothes washer market in the United States is more oligopolistic or monopolistically competitive than monopolistic. There is a rich literature demonstrating that even when the monopoly assumption is relaxed to allow for a 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 of switching from the preferred brand. 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's 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.

Additionally, others have demonstrated the theoretical impact of minimum quality standards on quality-differentiated markets that are not monopolistic, but rather oligopolistic or monopolistically competitive. In particular Ronnen (1991) develops a model of an industry in which two firms (later extended to some finite k number of firms in the market and an infinite number of potential entrants) 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 (1991), but while Ronnen (1991) showed that consumers necessarily gain from a minimum quality standard, Crampes and Hollander (1995) 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, implying that using the predictions from the monopoly model is a reasonable proxy for the non-monopoly imperfect competition setting.

2.4 Testable Price Predictions of a Combined Increase in the Minimum and ENERGY STAR Standards

In this section I take the results presented in Sections 2.1 and 2.2, which provided predictions of the affect on market prices of either the minimum or ENERGY STAR standard changing separately, and combine the results to determine the price effect predictions when both these standards change simultaneously. Table 2 summarizes the price predictions of a simultaneous change in the minimum and ENERGY STAR standard in an imperfectly competitive market, while Table 3 outlines the corresponding predictions under perfect competition.

In a market with five consumer types and imperfect competition, Table 2 shows that a combined increase in both the minimum and ENERGY STAR standards should result in the aggregate effect of a price decrease for models decertified from ENERGY STAR (segment 2), and a price decrease for models that are close substitutes to those directly impacted by the minimum standard (segment 4). The price of the market segment for which the minimum standard is binding (segment 5) is predicted to see a price increase in nominal terms, although importantly it would be a decrease in efficiency-adjusted terms. The predictions for the market segments 1 and 3 are unclear.

In a perfectly competitive market on the other hand, as shown in Table 3, a combined minimum and ENERGY STAR standard increase should result in no price change for the highest efficiency segment (1), a price decrease for models decertified from ENERGY STAR (segment 2) and an ambiguous effect on segment 3 products. The primary difference between the predictions from the perfect competition model and the price discrimination model is the effect of the standard on the mid-low range of efficiency (here described as segment 4). The lowest segment for which the new minimum standard is binding (segment 5) should see an unambiguous increase in price under perfect competition. Additionally, while in the imperfect competition case the effect on the price of market segment 4 was an unambiguous price decrease, the prediction under perfect competition should be either that there is no price change for these products, which would be the result if type 5 consumers simply exit the market when p_5 increases, or that some marginal consumers of type 5 might respond to the price increase of the lowest market segment products by substituting to the next highest efficiency level, now that the price differential between these two market segments is less. This would create a positive demand shock in market segment 4, resulting in a price increase. Note that the same could be the case cascading upward all the way to segment 1.

Table 2: Imperfect Competition Price Predictions Following Increase in Minimum & ENERGY STAR Standards

Market Segment	Description of Market Segment	Price Prediction: Minimum Std	Price Prediction: ENERGY STAR Std	Price Prediction: Combined
1	ENERGY STAR → ENERGY STAR	↓	↑	Ambiguous
2	ENERGY STAR → Decertified	↓	↓	↓
3	Close substitutes to decertified	↓	Ambiguous	Ambiguous
4	Close substitutes to segment 5	↓	-	↓
5	Minimum standard binding	↑*	-	↑*

* While the model predicts an increase in prices for this segment in nominal terms, prices actually drop in efficiency-adjusted terms.

Note: Predictions of the price effects of a simultaneous increase in both the minimum and ENERGY STAR efficiency standard under imperfect competition across the energy efficiency spectrum of the market.

Table 3: Perfect Competition Price Predictions Following Increase in Minimum & ENERGY STAR Standards

Market Segment	Description of Market Segment	Price Prediction: Minimum Std	Price Prediction: ENERGY STAR Std	Price Prediction: Combined
1	ENERGY STAR → ENERGY STAR	-	-	-
2	ENERGY STAR → Decertified	-	↓	↓
3	Close substitutes to decertified	-	Ambiguous	Ambiguous
4	Close substitutes to segment 5	↑*	-	↑
5	Minimum standard binding	↑	-	↑

* This would be the case if we assume that some marginal consumers of type 5 might respond to the increase in the price of the lowest market segment of products by shifting to substitutes with a higher level of efficiency, now that the price differential between these two market segments are less. This would create a positive demand shock in market segment 4, resulting in a price increase in that market segment.

Note: Predictions of the price effects of a simultaneous increase in both the minimum and ENERGY STAR efficiency standard under perfect competition across the energy efficiency spectrum of the market.

2.5 Other Model Predictions

Tables 2 and 3 outline the primary price predictions differentiating a perfectly competitive market reaction from a market with imperfect competition and price discrimination, namely prices in the mid-low range of the market should increase under perfect competition and decrease under price discrimination. In this section I outline two additional testable predictions in this model. First, 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 market segments imposed by the quality distribution collapse following the new standard. Therefore, a second prediction is that there will be an increase in innovation and model proliferation in the highest efficiency range of the market following the new standard, as firms spread the efficiency distribution upwards in their attempt to re-establish a new optimal price-efficiency schedule.

Finally, the predictions of the price effects of a new minimum standard in the imperfectly competitive model are contingent on the supposition that firms have been price-discriminating and charging increasingly positive margins for higher levels of efficiency. If, however, the market has been otherwise forced to increase efficiency and/or reduce margins already, then changing the minimum efficiency standard should result in less of a downward price effect. This is relevant in this setting as the clothes washer market faced a change in the minimum and ENERGY STAR standards in 2004, and then again shortly thereafter in 2007. The model would therefore predict that the effects driven by price-discrimination should be most pronounced at the time of the 2004 standard change. This change would result in a depression of price margins and the firms may not have been able to re-establish an optimal pricing strategy fully by the time of the 2007 standard change. Therefore in 2007 one should expect to see less of the price effects predicted by the price discrimination model compared to 2004.

3 Data

I use POS data for clothes washers, dryers and room air conditioners (room ACs) from NPD Group.[6] These data are acquired from an incomplete set of retailers nationwide (a list of participating retailers can be found in Appendix 3). The data are aggregated to the national level and consist of monthly total revenue and total quantity sold observations by model number. The data also include information on some model characteristics, though for a subset of observations.

The NPD data for clothes washers were matched with energy usage data, measured in kilowatt-hours per year (kWh/year), by model number and year from the Federal Trade Commission (FTC) appliance energy database.

In order to control for changes in macroeconomic shocks to the appliance market, and to control for changes to the data mix of the NPD data, I use both dryers and room ACs as counterfactual groups.[7] Neither dryers nor room ACs had any adoption or effective dates

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

[7]Some retailers did enter or exit the data at different times in the series. NPD attempts to maintain consistency within the data over time, and I was assured by NPD that the large retailers do not change over the study period. Data are available for refrigerators and dishwashers as well. Unfortunately, dishwashers experienced a change in the test procedure used to determine compliance with standards right before January 2004, which resulted in price volatility for this product at that time. Additionally the ENERGY STAR standard for dishwashers changed January 1st, 2007, and changed for refrigerators on January 1st, 2004. This makes these appliances unusable as counterfactual groups.

for either minimum efficiency or ENERGY STAR standard changes over the range of the study period. There are issues with using either of these appliances as counterfactuals. First, room ACs, while arguably a relatively independent product from clothes washers, did experience more general price volatility and were more prone to seasonal price variability. Second, clothes washers and dryers are not independent markets, and so using dryers as a comparison to measure the market impacts of the standard for clothes washers is likely to be more conservative than using another, less linked, product. This is because dryers and washers are likely compliments, and therefore their prices and sales should be positively correlated.

The NPD data, while extensive in some ways, are imperfect in others. In particular, a large subset of the model numbers are masked to ensure anonymity of retailers. These models cannot be matched to the FTC energy usage data, and therefore must be omitted from my analysis (40% of the observations in the focus period of this analysis must be dropped for this reason). Of the models that do have fully detailed model numbers, not all are included in the FTC energy usage database, and must therefore be omitted as well (82% of the data with fully detailed model numbers for clothes washers in the focus period of this analysis are successfully matched to FTC data). In order to maintain comparability between clothes washers and the counterfactual appliance groups, masked model numbers were also dropped from the dryer and room AC data.[8]

As mentioned in Section 1, the energy measures used to determine the compliance of washer models with minimum and ENERGY STAR standards are the EF, MEF and WF. Unfortunately, data on these efficiency measures are not available for the majority of the models in the NPD data during this period. It is therefore impossible to identify which models meet either the minimum standard or the ENERGY STAR standard specifically at each time period in the sample. The available energy efficiency metric is the FTC measure of kWh/year used by each washer model in each year. This measure does not correspond directly to any of the DOE efficiency measures (EF, MEF or WF) used to set the standards. However, the FTC kWh/year measure is an important indicator of energy consumption, particularly from the perspective of the consumer purchase decision; it is the FTC measure that is required to be posted on products at the retail outlet to inform consumers about the energy use of their potential purchases. In this study therefore, models are stratified based on this FTC metric of energy use as a proxy for determining the direct impact of the change in standards across the market. This will be discussed in more detail in Section 4.2.

There are 699 unique clothes washer models, 820 unique dryer models, and 595 unique room AC models used in the analysis. An individual appliance model number in these data uniquely identifies a particular design. Therefore, any change in characteristics of an individual model over time would be a small internal change that would not otherwise affect the appearance of the product. Even small internal changes may result in a change in the

[8]Appendix 4 provides figures showing the comparison of price (as represented by average revenue from the NPD data) for those models included in the full analysis, and those models omitted. Generally, models used in the analysis tended to be slightly more expensive than those omitted for all three appliances, though more so for clothes washers and dryers. In Appendix 6 results from a robustness check – wherein none of the data are omitted – analogous to the estimation presented in Section 4.1 are reported. This is done in order to demonstrate that the average effects of the new standards on prices were not driven only by the subset of the data used in the primary analysis.

washer model number, depending. Of the clothes washer models in the data that do have a set of descriptive characteristics, none of the observable characteristics of a given washer model change over time except one: the FTC energy usage measure. Even in this case it only changes slightly for a handful of models. Therefore, controlling for model-specific fixed effects will control for more or less all relevant characteristics of the models from a consumer perspective. If a major characteristic changes, then this results in a new unique model number.

Table 4 shows summary statistics for the data used in the full analysis. The changes to clothes washer standards are indicated by the double vertical lines between 2003 and 2004, and between 2006 and 2007 in the table. The average deflated prices of clothes washers and dryers have risen on average between 2003 and 2007; washers cost $626 in 2009 dollars on average in 2003, and that increased to $690 in 2007. Similarly dryers cost $465 in 2009 dollars on average in 2003 increasing to $590 in 2007. On the other hand, the average prices of room ACs went down slightly over this time period, costing $392 on average in 2009 dollars in 2003 and $366 on average in 2009 dollars in 2007. The efficiency of clothes washers, as measured by the average FTC kWh/year usage of these products, has steadily improved over this period as well, averaging 714 kWh/year usage in 2003 and improving to a usage of only 312 kWh/year on average in 2007. Additionally, the prevalence of front-loading washer models has steadily increased over time, making up 15% of observations in 2003 and increasing to 46% of observations in 2007. Finally, the standards for clothes washers are different for compact models versus standard-sized models. However, of observations in the data for which the capacity variable is available, only 0.95% are for compact models. Therefore, the vast majority of models in the data are standard-class models (capacity greater than 1.6 cubic feet).

Table 4: Summary Statistics

Clothes Washers

	2003		2004		2005		2006		2007	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Price	626.00	374.96	680.51	408.93	712.64	396.05	703.92	377.71	690.23	335.79
FTC kWh/year	714.12	275.41	446.88	192.77	392.95	161.06	367.97	154.12	311.63	133.06
Share TL	0.85	0.36	0.75	0.43	0.68	0.47	0.64	0.48	0.54	0.50
Percent of Clothes Washers that are Compact (<1.6 cubic feet) in data: 0.95%										

Counterfactual Appliances

	2003		2004		2005		2006		2007	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Dryer Price	465.18	204.52	519.84	265.89	537.25	248.75	548.57	249.12	589.73	257.33
Room AC Price	391.78	219.08	335.78	210.21	334.32	210.13	359.80	211.67	366.46	217.84

Note: Summary statistics of NPD data for clothes washers, dryers, and room ACs. All prices are calculated as average revenue (total revenue divided by total units sold in a given month), and are deflated using the CPI with a base period of December 2009. “Share TL” is the share of observations consisting of sales of top-loading washers as opposed to front-loading washers. Double vertical lines indicate when the minimum and energy star standards changed for clothes washers.

4 Results

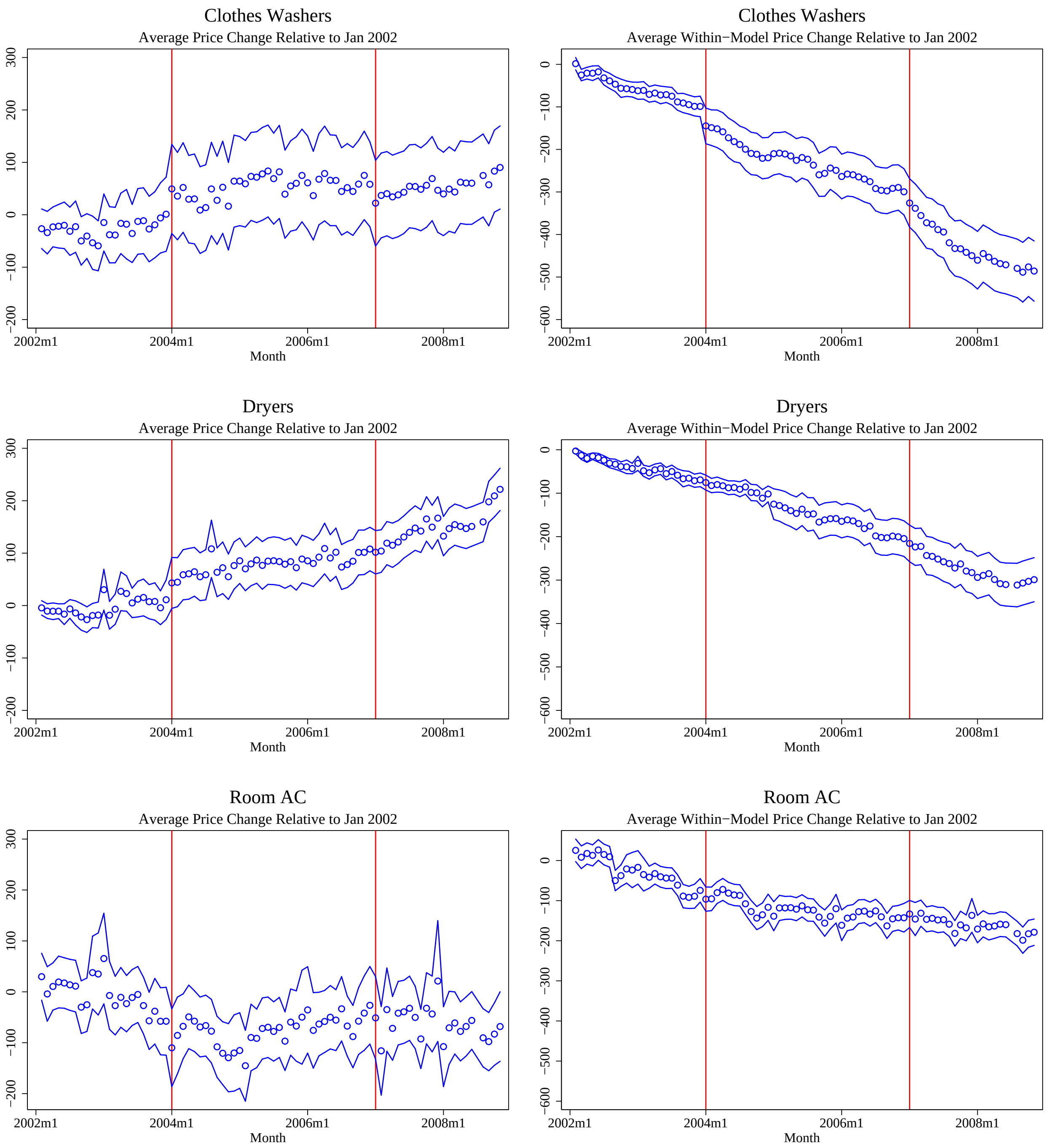
Before exploring the empirical results that address the price change predictions in different efficiency-based market segments, I do a baseline analysis showing the effect of the standard changes on the average clothes washer prices in 2004 and 2007. These results are presented in Section 4.1. I then progress to a deeper exploration of the price changes, allowing a differentiated price effects across efficiency categorizations. This analysis is presented in Section 4.2. In both cases, average and efficiency-differentiated results, I use four estimation strategies to capture the scope of price changes. I estimate four price changes at the time of the new standard: first, the market average price change not controlling for any model characteristics; second, the average within-model price change by controlling for model-specific fixed effects; third, the market average price change again, but rather than looking at first-differences, I use a difference-in-difference (DD) model using dryers and room ACs as counterfactual appliance groups, and finally, the average within-model price change again, but using the DD model and counterfactual groups as well.

Intuitively, estimating the effect of the standard with and without fixed effects captures a full picture of the price changes concurrent with the implementation of the new standard; the firms in this market may react to the standard in one, or both, of two possible ways: they can change the mix of models in the market, and they can change the price-efficiency schedule of existing models in the market. The analysis with no fixed effects captures the average market price change both at the intrinsic (price change of existing models) and extrinsic (change in model mix) margins. This analysis answers the question, "If a consumer walked into a store right after the new standard, what is the change in the price distribution across all models they would face relative to if they walked into the store right before the standard?" The analysis with fixed effects, on the other hand, controls for all time-invariant characteristics of a given model, which ends up being more or less all relevant model characteristics other than prices and standard compliance. Therefore, it will not capture any price changes due to a change in model mix, but will isolate the portion of the average price change that is due to that of existing models. This analysis answers the question, "If a consumer walked into a store right after the new standard, what is the change in the price of model X they would face relative to if they walked into the store right before the standard?"

Figure 3 shows the clothes washer, dryer and room AC price trends over the study period. The left-hand column shows the overall market average price trends while the right-hand column shows the within-model price trends. As can be seen in the left-hand panels of Figure 3, the average dryer price appears to have risen more quickly than that of clothes washers, while the average room AC price does not appear to have risen at all over this period. I account for this by allowing overall price trends to vary by appliance.

The average clothes washer price at the 2004 standard change appears to bump up slightly, but so does the dryer price at that point, so it is unclear whether this might be in part due to some macroeconomic jump, or due to the change in data mix. On the other hand the average market room AC price appears to dip down slightly at the time of the 2004 standard change, but only for a month or two. At the time of the standard change in 2007 it appears that average clothes washer prices dipped down notably, but there was no discernible change for either dryers or room ACs.

Figure 3: Market Average and Within-Model Price Trends



Note: Market-average (left column) and within-model (right column) price trends for clothes washers (top row), dryers (middle row) and room ACs (bottom row) between 2002 and 2008. All prices are real (deflated using the CPI with December 2009 base-period), and are shown relative to the average price level in January 2002. The solid vertical lines show when the standard changed for clothes washers (January 2004 and January 2007). The solid lines indicate 95% confidence intervals.

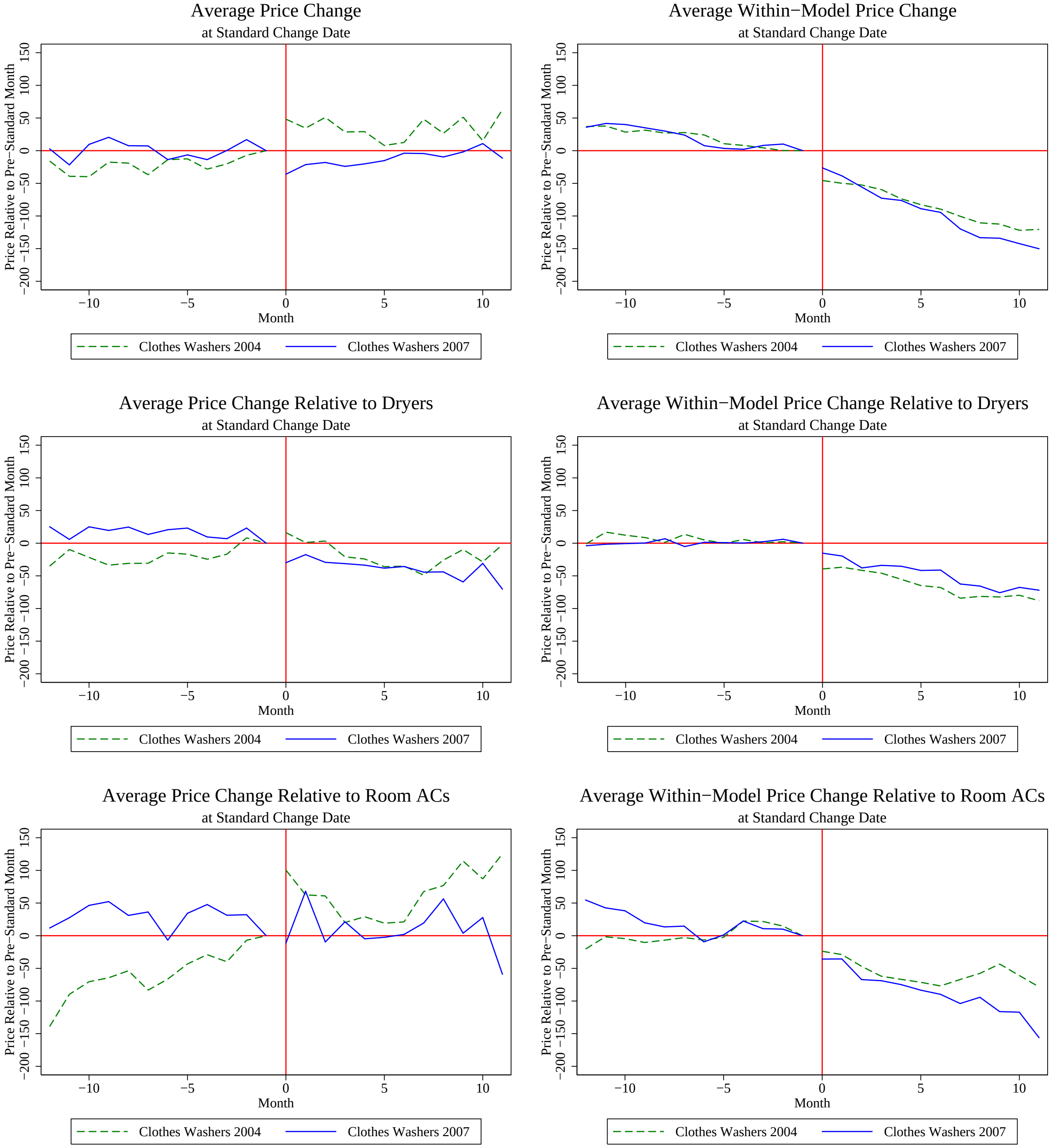
Turning now to the right-hand column of Figure 3, the within-model prices drop steadily over this time period, though less so for room ACs than clothes washers or dryers. Firms with market power have an incentive to provide new efficient products at a high price early, and then reduce the price over time, as this allows them to price-discriminate between high and low-type consumers intertemporally. Consumers with a higher valuation for efficiency will purchase the products early, at a higher price, and then consumers with a lower valuation for efficiency will wait to purchase the product until the price drops (Landsberger and Meilijson, 1985; Kühn, 1998; Koh, 2006). This could be a factor in the downward trend of within-model deflated prices. Another factor might be "learning" in the production process, suggesting that production costs drop over time as suppliers fully optimize production of a new technology (an excellent review of the literature on learning/experience curves can be found in Taylor and Fujita (2013)). Aside from the overall average within-model price drop over this period, note the visible price drop, downward trend-break, or both, at both standard change dates for clothes washers but not for dryers or room ACs. The next section explores these price effects more rigorously.

4.1 Average Price Effect of Standard Change

In this section I estimate the short-run price effect at the time of the combined minimum and ENERGY STAR standard changes, without differentiating across efficiency levels. Figure 4 shows the price changes at both instances of the standard changing. The standard changes when time (measured in months) is equal to zero. The price change at the standard is shown relative to the month just preceding the standard change. The top two panels of Figure 4 show the first-differences price change within clothes washers (i.e. without using a counterfactual). The middle two panels of Figure 4 show the price change relative to dryers as a counterfactual, and the bottom two panels do the same using room ACs as the counterfactual. The left-hand panels of Figure 4 show the average market price change, without controlling for anything about the specific models. The right-hand panels of Figure 4 show the within-model price changes by including model-specific fixed effects.

In all cases, and also in the regression results presented below, I limit the analysis to the time frame immediately around the standard, specifically one year prior to the standard change and one year after. I do this because there are several different policy changes affecting clothes washers at different points over the period for which I have data. Also, in 2008 and beyond, the prices off all appliances start becoming more erratic, possibly due to economic volatility. I therefore choose to focus on the short-run effect of the change in standard to isolate the analysis from these other factors. This is also the most relevant lens for testing the imperfect competition price-discrimination model predictions presented in Section 2.

Figure 4: Price Change at Standard Change Dates



Note: The change in market-average (left column) and within-model (right column) price relative to the month just preceding each standard. All prices are real (deflated using the CPI with December 2009 base-period). The change in standard went into effect at month 0 in all cases. This price change is shown within clothes washers only (top row), relative to dryers (middle row), and relative to room ACs (bottom row).

As can be see in Figure 4, the average effect on prices at the time of the new standard, particularly within-model, is downward. If the concurrent change in either counterfactual price is not used as a reference, then it appears that prices increased for clothes washers as a result of the 2004 standard. However, after controlling for the concurrent dryer price change the upward change in clothes washer prices is dampened. The positive price effect of the 2004 standard when depicted relative to room ACs as the counterfactual group is still present, however there is a lot of noise and while prices jump up for the first two or three months, they drop down again quickly thereafter. While results for the average price effect in the left-hand panels of Figure 4 appear to be more ambiguous, the within-model price changes appear to consist of an immediate downward discontinuous drop in prices just at the implementation date of both new standards. Additionally, there appears to be a downward trend-break in within-model prices at the time of both standards.

In order to quantify the effects shown graphically in Figure 4, I conduct a series of OLS regressions, the results of which are presented in Tables 5 and 6. The dependent variable in all cases is price, which has been deflated using the CPI with December 2009 as a base period. To be explicit, the full estimating equation is presented in Equation 8, where 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 room ACs). The term $Trend_t$ is a linear time trend; $Standard_t$ is a dummy variable that turns on at the time the new standard takes effect, and $Trend_t * Standard_t$ is a term that is equal to zero for all observations up until the time of the standard and begins increasing by one unit each month following the standard. 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 $\beta_1 = \beta_2 = \beta_3 = 0$ and μT_i is omitted.

The coefficients of interest are the coefficients on $T_i * Standard_t$ and $T_i * Standard_t * Trend_t$. The coefficient on $T_i * Standard_t$ is interpreted as the discontinuous level change, in dollars, of the price at the time of the new standard, and the coefficient on $T_i * Trend_t * Standard_t$ 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.

$$\begin{aligned} p_{it} = &\alpha + \beta_1 Trend_t + \beta_2 Standard_t + \beta_3 Standard_t \cdot Trend_t + \mu T_i \\ &+ \psi T_i \cdot Trend_t + \delta T_i \cdot Standard_t + \phi T_i \cdot Standard_t \cdot Trend_t + \gamma_i + \varepsilon_{it} \end{aligned} \tag{8}$$

Table 5 shows the results with no fixed effects and Table 6 shows the results with fixed effects. In both Table 5 and 6 I present six sets of regression results. Columns (1) and (4) in both tables present the results of the first-difference regressions that do not include a counterfactual; Columns (2) and (5) in both tables present the results of the DD regressions including dryers as the counterfactual, and finally Columns (3) and (6) in both tables present the results of the DD regressions including room ACs as the counterfactual. Columns (1), (2) and (3) in both tables look at the effect of the 2004 change in standard. Columns (4), (5) and (6) look at the effect of the 2007 change in standard.

Table 5: Average Price Effect at New Standard Effective Dates

	2004 Standard Change			2007 Standard Change		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Var: Price	No Controls	Dryers as Controls	Room AC as Controls	No Controls	Dryers as Controls	Room AC as Controls
T		146.7***	185.8***		161.9***	345.9***
		(34.94)	(36.50)		(35.93)	(35.96)
Trend		-0.418	-6.444***		1.219	0.434
		(1.506)	(2.135)		(1.376)	(2.171)
Standard		43.47**	18.30		1.271	-8.558
		(18.11)	(18.15)		(10.46)	(22.03)
Trend * Standard		2.877	0.295		4.621**	1.850
		(2.447)	(2.983)		(2.176)	(3.586)
T * Trend	2.043	2.461	8.487**	0.103	-1.116	-0.331
	(2.548)	(2.959)	(3.323)	(2.027)	(2.449)	(2.970)
T * Standard	40.83	-2.635	22.54	-29.49*	-30.76	-20.93
	(35.64)	(39.96)	(39.98)	(16.66)	(19.66)	(27.62)
T * Trend * Standard	-1.872	-4.749	-2.167	2.651	-1.970	0.801
	(4.010)	(4.696)	(4.997)	(2.885)	(3.612)	(4.602)
Constant	614.2***	467.5***	428.4***	703.3***	541.4***	357.4***
	(31.96)	(14.15)	(17.65)	(31.41)	(17.48)	(17.52)
Model Fixed Effects	N	N	N	N	N	N
Observations	3,637	7,283	6,422	4,793	10,655	7,129
R-squared	0.005	0.068	0.165	0.001	0.044	0.198

Standard errors in parentheses clustered by model number

*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions estimating the concurrent effect of the new standard (either 2004 or 2007) on the market average price of clothes washers. Columns (1) and (4) only include clothes washer models, while Columns (2) and (5) look at the effect relative to dryers, and Columns (3) and (6) look at the effect relative to room ACs. No controls or fixed effects are included.

Looking first at the results presented in Table 5, there were almost no statistically significant changes in the market average price of clothes washers at either standard. We see from these results that there was a slight increase in the market average price of washers at the time of the 2004 standard, though it is not statistically significant either in the first-differences specification, nor relative to dryers or room ACs. There was a slight price drop on average for clothes washers at the time of the 2007 standard, though it is marginally significant in only one specification. We see confirmation of what is clear from Figures 3 and 4, that prices of room ACs were trending down relative to prices of clothes washers around the time of the 2004 standard, but there are no significant trend-breaks at the time of the standard changes for clothes washers in any specification. These results indicate that the distribution of prices faced by the consumer did not shift significantly at the time of either standard. If the standard resulted in cheaper, less-efficient models simply being dropped from the market with no additional price or menu adjustment, we should see an increase in prices on average at the time of the standard. This apparently was not the case.

Table 6: Within-Model Price Effect at New Standard Effective Dates

	2004 Standard Change			2007 Standard Change		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Var: Price	No Controls	Dryers as Controls	Room AC as Controls	No Controls	Dryers as Controls	Room AC as Controls
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)
Trend * Standard		0.413	0.762		-2.438**	-0.744
		(0.974)	(1.171)		(0.984)	(1.306)
T * Trend	-4.342***	-0.743	2.741**	-5.754***	-0.595	-3.426***
	(0.815)	(0.976)	(1.220)	(0.835)	(1.056)	(1.158)
T * Standard	-36.58***	-34.90***	-72.68***	-13.23**	-10.28	-27.73***
	(11.16)	(11.87)	(13.34)	(6.383)	(7.639)	(9.981)
T * Trend * Standard	-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	739.1***	634.3***	603.6***	799.2***	714.6***	663.0***
	(11.36)	(5.985)	(6.907)	(9.330)	(5.389)	(6.549)
Model Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	3,637	7,283	6,422	4,793	10,655	7,129
R-Squared	0.235	0.209	0.223	0.319	0.300	0.293
Number of Models	418	736	790	431	959	751

Standard errors in parentheses clustered by model number

*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions estimating the concurrent effect of the new standard (either 2004 or 2007) on the market average within-model price of clothes washers. Columns (1) and (4) only include clothes washer models, while Columns (2) and (5) look at the effect relative to dryers, and Columns (3) and (6) look at the effect relative to room ACs. Model-specific fixed effects are included in all specifications.

I now turn to the results of the regressions including fixed effects, presented in Table 6. In all but one specification there is both a statistically significant discontinuous drop in within-model prices at the time of the standard, and a statistically significant downward trend-break in the rate at which within-model prices of clothes washers are dropping over time starting at the time of each new standard. In particular, within-model prices of washers dropped \$36.58 on average at the time of the 2004 standard; this drop was \$34.90 relative to the concurrent change in within-model dryer prices, and \$72.68 relative to the concurrent change in within-model room AC prices. At the time of the 2007 standard change the within-model average price drop was less: \$13.23 (not significant relative to dryers and \$27.73 relative to room ACs). At the time of the 2004 standard change, within-model clothes washer prices began dropping between \$3 and \$4 more quickly each month after the standard relative to before in all specifications. This downward trend-break was slightly larger in magnitude at the time of the 2007 standard (between \$4 and \$7 per month).

Overall, it is clear these standards appeared to be associated with relatively strong downward pressure on within-model prices, and no evidence of an increase in overall average prices.

It would be difficult to claim, given these results, that tightening the standards resulted in an increase in appliance prices on average during these two standard changes. This would be puzzling if we assumed that the market for appliances was perfectly competitive. I now turn to an analysis of these effects looking at the heterogeneity across efficiency levels in the market. These results will begin to speak directly to the predictions from the price discrimination model presented in Section 2.

4.2 Testing Model Prediction: Effects on Prices by Efficiency Level

In this section I address the testable predictions of price changes derived in Section 2.4 directly. To this end I break the appliance market into five categories based on the FTC kWh/year energy use measure and explore the differential effects of the new standards across these efficiency groups. Given the framing of the predictions from the model presented in Section 2, it would be ideal if I were able to identify which models were ENERGY STAR qualified and/or met the minimum standard at each time period. Unfortunately, the energy use data currently available, as mentioned above, is the FTC's kWh/year consumption measure. This is not the same energy use measure used to determine the cut-offs for the minimum and ENERGY STAR standards. For this reason, I must approximate the five market segments defined in the model as best I can. To this end, I categorize all the models using quintile cut-offs of energy consumption based on the FTC kWh/year measure right around each standard. In order to provide the most consistent categorization across time, I do the following: first, I calculate the quintile cut-offs (20th, 40th, 60th, and 80th percentiles) of energy use across the sample in the year just prior to the standard for each standard separately. I then categorize all models with observations of their FTC model number[9] in that year prior to the standard, based on these cut-offs (i.e. a FTC model number whose energy consumption is less than the 20th percentile is placed in Group 1, a FTC model number with energy consumption between the 20th and 40th percentile cut-offs is placed in Group 2, etc). Then, if there are any FTC model numbers that do not appear in the data until after the new standard, I calculate quintile cut-offs for the year just following the standard for each standard separately, and categorize the models that have not already been categorized. Therefore, in the end, each model with observations within the two year window around each standard is given a unique group categorization (Group 1, 2, 3, 4 or 5). The categorization is primarily based off the pre-standard energy use distribution, but is filled in with a categorization based off the post-standard energy use distribution only for models

[9]A model number from the FTC database generally matches to more than one model number in the NPD data. I categorize the models into efficiency groups based on the FTC model number, rather than the NPD one. This is because, particularly in 2004, a large number of models exited the market the month before the standard, and re-entered the market the month following the standard with the exact same model number except for one or two characters. These pairs of models are matched to the same FTC model number, indicating that the models are more or less identical in terms of consumer features, but perhaps had internal changes to make them more efficient. Therefore if a model is adapted in this way, both occurrences of this model are categorized into the same efficiency group, as what I'm interested in is looking at changes to the efficiency group as determined before the standard at the time the standard is imposed. This categorization method accomplishes this.

that did not appear in the data prior to the standard (9.34% of data used in the estimation were filled in with post-standard categorizations).

After categorizing each model into one of the efficiency groups (1, 2, 3, 4 or 5, where Group 1 is the highest efficiency group and Group 5 is the lowest efficiency group), I run a series of regressions that mirror those I presented in Section 4.1. In particular, the dependent variable in all cases is still the deflated price. In all regressions I include a linear overall time trend, which I allow to differ across efficiency market segments ($Group_{ji} * Trend_t$), where $Group_{ji}$ is a dummy variable equal to one if model i is categorized into Group j, $\forall j \in \{1, 2, 3, 4, 5\}$, and zero otherwise. Now, instead of estimating the average effect of the standard, I estimate the effect of the standard differentiated across the five efficiency groups, captured by the variable $Group_{ji} * Standard_t$, where $Standard_t$ is still a dummy variable equal to zero prior to the standard, and equal to one for all observations thereafter. The variable $Trend_t * Standard_t$ is still equal to zero for all observations up until the time of the standard and begins increasing by one unit each month following the standard, however I now look at this change-in-trend term differentiated across groups, so the relevant variable is now $Group_{ji} * Trend_t * Standard_t$. When I include a counterfactual group, I include variables $Trend_t$, $Standard_t$ and $Trend_t * Standard_t$ to capture the average change in counterfactual prices around the standard. Finally, in the regressions without fixed effects I include the variables $Group_{ji}$, $\forall j \in \{1, 2, 3, 4, 5\}$. The coefficients of interest are the coefficients on $Group_{ji} * Standard_t$ and $Group_{ji} * Trend_t * Standard_t$. Note that while I still use a counterfactual, dryers and room ACs are not categorized into any efficiency groups, so the effect on the prices of a given efficiency group when interpreted relative to a counterfactual should be interpreted as relative to the average change in counterfactual prices across the whole counterfactual market. Once again to be explicit, the full estimating equation is presented in Equation 9, where p_{it} is still deflated price at time t of model i. In the regressions with fixed effects the terms $\mu_j Group_{ji}$ are omitted; in the regressions without fixed effects γ_i is omitted, and for regressions with no counterfactual group $\beta_1 = \beta_2 = \beta_3 = 0$ and $\mu_3 Group_{3i}$ is omitted. The results of the regressions without fixed effects are presented in Table 7 and the results of the regressions with fixed effects are presented in Table 8.

$$\begin{aligned} p_{it} =& \alpha + \beta_1 Trend_t + \beta_2 Standard_t + \beta_3 Standard_t \cdot Trend_t + \sum_{j=1}^{5} \mu_j Group_{ji} \\ &+ \sum_{j=1}^{5} \psi_j Group_{ji} \cdot Trend_t + \sum_{j=1}^{5} \delta_j Group_{ji} \cdot Standard_t + \sum_{j=1}^{5} \phi_j Group_{ji} \cdot Standard_t \cdot Trend_t + \gamma_i + \varepsilon_{it} \end{aligned} \tag{9}$$

Table 7: Average Price Effects at New Standard Effective Dates: Efficiency-Level Specific Results

	2004 Standard Change			2007 Standard Change		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Var: Price	No Controls	Dryers as Controls	Room AC as Controls	No Controls	Dryers as Controls	Room AC as Controls
Trend		737.5***	776.5***		537.3***	721.3***
		(112.7)	(113.2)		(72.58)	(72.64)
Standard		150.6*	189.6**		489.6***	673.6***
		(88.09)	(88.74)		(74.24)	(74.31)
Trend * Standard		93.38	132.4*		74.98	259.0***
		(67.75)	(68.58)		(54.29)	(54.34)
Group 1 (Most Efficient)	644.1***	7.939	46.97	462.3***	-4.042	179.9***
	(130.2)	(49.26)	(50.39)	(87.34)	(67.80)	(67.86)
Group 2	57.21	5.625	44.66	414.6***	-128.1***	55.87*
	(109.5)	(29.18)	(31.04)	(88.74)	(28.93)	(28.97)
Group 3		-0.418	-6.444***		1.219	0.434
		(1.508)	(2.138)		(1.377)	(2.174)
Group 4	-85.44	43.47**	18.30	-79.03	1.271	-8.558
	(81.51)	(18.14)	(18.18)	(83.40)	(10.47)	(22.06)
Group 5 (Least Efficient)	-87.76	2.877	0.295	-203.1***	4.621**	1.850
	(71.14)	(2.450)	(2.987)	(56.42)	(2.178)	(3.591)
Group 1 * Trend	4.265	4.682	10.71	-6.986	-8.206	-7.421
	(7.629)	(7.761)	(7.909)	(4.870)	(5.052)	(5.328)
Group 2 * Trend	2.306	2.724	8.750	-15.92***	-17.14***	-16.35***
	(6.241)	(6.407)	(6.585)	(4.266)	(4.476)	(4.784)
Group 3 * Trend	-4.804	-4.386	1.640	4.841	3.622	4.407
	(4.613)	(4.844)	(5.076)	(4.376)	(4.581)	(4.883)
Group 4 * Trend	-3.300	-2.882	3.144	-4.915	-6.134	-5.349
	(2.024)	(2.521)	(2.942)	(3.796)	(4.032)	(4.371)
Group 5 * Trend	-0.665	-0.247	5.779**	1.584	0.364	1.149
	(1.830)	(2.368)	(2.812)	(1.363)	(1.936)	(2.565)
Group 1 * Standard	-38.25	-81.72	-56.55	-20.19	-21.46	-11.63
	(84.51)	(86.26)	(86.29)	(35.32)	(36.78)	(41.62)
Group 2 * Standard	48.34	4.871	30.04	-10.40	-11.67	-1.845
	(66.78)	(69.07)	(69.09)	(41.98)	(43.20)	(47.39)
Group 3 * Standard	94.16	50.69	75.86	-35.77	-37.04	-27.21
	(73.63)	(75.68)	(75.70)	(22.48)	(24.76)	(31.48)
Group 4 * Standard	-36.65*	-80.12***	-54.95*	28.82	27.55	37.38
	(21.93)	(28.43)	(28.46)	(25.17)	(27.22)	(33.45)
Group 5 * Standard	-19.78	-63.25*	-38.08	-43.15**	-44.43**	-34.60
	(31.71)	(36.47)	(36.49)	(19.28)	(21.91)	(29.29)
Group 1 * Trend * Standard	-13.04	-15.92*	-13.33	1.191	-3.430	-0.659
	(9.028)	(9.336)	(9.493)	(6.226)	(6.586)	(7.182)
Group 2 * Trend * Standard	-5.029	-7.906	-5.324	5.180	0.559	3.330
	(7.488)	(7.863)	(8.048)	(6.262)	(6.619)	(7.213)
Group 3 * Trend * Standard	-0.387	-3.264	-0.682	-2.055	-6.675	-3.905
	(6.503)	(6.936)	(7.145)	(6.489)	(6.834)	(7.411)
Group 4 * Trend * Standard	3.188	0.311	2.893	0.446	-4.174	-1.404
	(2.959)	(3.837)	(4.201)	(3.736)	(4.319)	(5.179)
Group 5 * Trend * Standard	-5.317*	-8.195**	-5.612	-2.291	-6.912**	-4.141
	(3.057)	(3.913)	(4.270)	(2.579)	(3.372)	(4.419)
Constant	560.9***	467.5***	428.4***	616.4***	541.4***	357.4***
	(66.39)	(14.17)	(17.68)	(51.48)	(17.50)	(17.54)
Model Fixed Effects	N	N	N	N	N	N
Observations	3,073	6,719	5,858	4,493	10,355	6,829
R-squared	0.501	0.410	0.509	0.364	0.253	0.444

Standard errors in parentheses clustered by model number
*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions estimating the concurrent effect of the new standard (either 2004 or 2007) on the average price of clothes washers differentiated across efficiency categories. Columns (1) and (4) only include clothes washer models, while Columns (2) and (5) look at the effect relative to dryers, and Columns (3) and (6) look at the effect relative to room ACs. No controls or fixed effects are included other than the efficiency categorizations.

I first discuss the results from the efficiency-level price regressions with no fixed effects, these regressions are presented in Table 7. There were no statistically significant average price changes within any of the three highest efficiency segments (Groups 1, 2 or 3) at either standard change. On the other hand, average prices dropped for either Group 4 or Group 5 (the least efficient market segments), or both, in all but one specification. In particular, Group 4 average prices dropped \$36.65 (\$80.12 relative to dryer, and \$54.95 relative to room ACs) at the 2004 standard change, but did not change significantly at the 2007 standard change. Additionally, Group 5 average prices dropped significantly \$43.15 (\$44.43 relative to dryer, and not significantly relative to room ACs) at the 2007 standard change, and also experienced a marginally significant \$63.25 price drop relative to dryers at the 2004 standard change.

There is slight evidence of a downward trend-break in two market segments. In particular, there was a marginally significant downward trend-break in Group 1 average prices of \$15.92 per month relative to dryers following the 2004 standard. Also for Group 5 there was a downward trend-break of \$5.32 per month in the first differences regression (\$8.20 relative to dryers) at the 2004 standard change, and \$6.91 relative to dryers at the 2007 standard change. However, realize that in general mid-high efficiency categories, particularly Group 2, tended to have average prices that trended down more quickly overall relative to all other categories and relative to both counterfactuals at a rate of between \$15 to \$17 per month over the 2006-2007 two year period.

Note, once again, that if the standard resulted only in cheaper low-efficiency models being dropped from the market – with no other price or menu adjustments – the lowest efficiency categories would be expected to experience a price increase on average. These results begin to paint a very different picture, indicating that the downward pressure on prices at the time of the standard changes tended to be driven by these least efficient categories. This story is only strengthened when looking at the results for the within-model price changes presented in Table 8 discussed next.

I now turn to the results of the efficiency-group specific regressions including fixed effects, presented in Table 8. In addition to fixed effects, I also control for the FTC kWh/year measure of efficiency in the Column (1) and (4) regressions. This is because, as mentioned above, the kWh/year measure does change within-model for a handful of models. I cannot include this variable in the estimation when counterfactuals are included in Columns (2), (3), (5) or (6) because this variable is not defined for dryers or room ACs.

Table 8: Within-Model Price Effects at New Standard Effective Dates: Efficiency-Level Specific Results

	2004 Standard Change			2007 Standard Change		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Var: Price	No Controls	Dryers as Controls	Room AC as Controls	No Controls	Dryers as Controls	Room AC as Controls
Trend		-3.600***	-7.083***		-5.159***	-2.328***
		(0.548)	(0.905)		(0.648)	(0.796)
Standard		-1.683	36.10***		-2.954	14.50*
		(4.285)	(7.228)		(4.204)	(7.638)
Trend * Standard		0.413	0.762		-2.438**	-0.744
		(0.973)	(1.171)		(0.984)	(1.307)
Group 1 (Most Eff) * Trend	-6.720*	-3.105	0.378	-9.077***	-3.957*	-6.787***
	(3.824)	(3.832)	(3.949)	(2.144)	(2.248)	(2.315)
Group 2 * Trend	-4.161*	-0.170	3.313	-11.40***	-6.138**	-8.968***
	(2.229)	(2.189)	(2.330)	(2.250)	(2.382)	(2.447)
Group 3 * Trend	-3.042***	0.699	4.182***	-5.331***	0.281	-2.550
	(0.835)	(0.953)	(1.201)	(1.423)	(1.618)	(1.695)
Group 4 * Trend	-4.912***	-1.858*	1.625	-2.378***	2.936***	0.106
	(0.995)	(1.068)	(1.297)	(0.825)	(1.025)	(1.130)
Group 5 (Least Eff)* Trend	-1.718	1.693	5.176***	-2.077**	3.082**	0.252
	(1.141)	(1.245)	(1.450)	(1.033)	(1.218)	(1.311)
Group 1 * Standard	-30.83	-28.26	-66.04**	2.391	4.781	-12.67
	(28.63)	(28.89)	(29.84)	(16.17)	(16.68)	(17.99)
Group 2 * Standard	-27.87	-20.48	-58.27	-7.496	-9.252	-26.71
	(36.17)	(36.42)	(37.36)	(19.34)	(19.24)	(20.44)
Group 3 * Standard	-41.34***	-14.38	-52.17***	-23.93*	-26.78**	-44.23***
	(15.04)	(11.87)	(13.35)	(13.12)	(12.20)	(13.85)
Group 4 * Standard	-95.64***	-90.51***	-128.3***	-8.402	-6.722	-24.18**
	(27.47)	(27.50)	(28.47)	(8.242)	(9.000)	(11.09)
Group 5 * Standard	-60.06***	-34.64**	-72.42***	-25.63**	-22.66*	-40.12***
	(17.66)	(15.32)	(16.57)	(12.48)	(13.15)	(14.72)
Group 1 * Trend * Standard	-6.157	-6.582	-6.931	-5.921**	-3.450	-5.144*
	(4.446)	(4.516)	(4.620)	(2.807)	(2.977)	(3.123)
Group 2 * Trend * Standard	-3.808	-4.566	-4.914	-9.932**	-7.714*	-9.408**
	(2.972)	(3.051)	(3.156)	(3.861)	(4.014)	(4.140)
Group 3 * Trend * Standard	-1.821	-2.378	-2.727	-4.639*	-2.423	-4.117
	(1.235)	(1.567)	(1.709)	(2.607)	(2.910)	(3.058)
Group 4 * Trend * Standard	0.741	0.872	0.524	-4.382***	-2.126	-3.820*
	(1.142)	(1.480)	(1.627)	(1.631)	(1.878)	(2.078)
Group 5 * Trend * Standard	-1.981	-1.962	-2.310	-4.143*	-1.706	-3.400
	(1.465)	(1.750)	(1.883)	(2.190)	(2.398)	(2.566)
FTC kWh/year	-0.121**			1.119*		
	(0.0526)			(0.571)		
Constant	835.8***	636.0***	602.5***	427.9**	713.7***	659.3***
	(36.10)	(6.454)	(7.541)	(191.6)	(5.101)	(5.975)
Model Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	3,073	6,719	5,858	4,493	10,355	6,829
R-squared	0.293	0.239	0.258	0.422	0.356	0.375
Number of Models	333	651	705	402	930	722

Standard errors in parentheses clustered by model number
*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions estimating the concurrent effect of the new standard (either 2004 or 2007) on the within-model price of clothes washers differentiated across efficiency categories. Columns (1) and (4) only include clothes washer models, while Columns (2) and (5) look at the effect relative to dryers, and Columns (3) and (6) look at the effect relative to room ACs. Model-specific fixed effects are included in all specifications. The FTC kWh/year variable is included only in the regressions presented in columns (1) and (4) because this variable in not defined for dryers or room ACs.

Once again, the results indicate that the drop in prices, here measured as the drop in within-model prices, appears to be driven by the lowest efficiency groups. There are no statistically significant discontinuous price drops for the two highest efficiency groups (1 or 2) in any specification save one, which indicates that Group 1 within-model prices dropped \$66.04 on average relative to the similar price drop of room ACs at the 2004 standard change. On the other hand, Groups 3, 4 and 5 experienced statistically significant price dropped in most cases. In particular, Group 3 experienced a price drop of \$41.34 at the 2004 standard change (no significant change relative to dryer, but a significant \$52.17 drop relative to room ACs). Additionally, Group 3 experienced a statistically significant within-model price drop at the 2007 standard change in all three specifications: \$23.93 in the first-differences regression, \$26.78 relative to dryers, and \$44.23 relative to room ACs. Group 4 saw the largest and across-the-board significant within-model price drops at the 2004 standard change: \$95.64 in the first-differences regression, \$90.51 relative to dryers and \$128.3 relative to room ACs. Group 4 also saw a significant \$24.18 within-model price drop at the 2007 standard change relative to room ACs. Finally, Group 5 experienced statistically significant within-model price drops in all cases. At the 2004 standard change this price drop ranged from \$34.64 relative to dryers to \$60.06 in first differences and \$72.42 relative to room ACs. Then, at the 2007 standard change, Group 5 experienced smaller within-model price drops ranging from a marginally significant \$22.66 relative to dryers and \$25.63 in first-differences, to \$40.12 relative to room ACs.

These coefficients can be a lot to keep track of, so I have provided Figure 5, which summarizes the results of these discontinuous changes in price coincident with the standard changes. This figure makes clear that the discontinuous drop in prices was driven by the lowest efficiency groups at both standard changes.

In terms of trend results it is clear again that the highest efficiency groups tended to have within-model prices that trended downward more quickly on average, both overall in the two years surrounding each standard, and in terms of a trend-break at the standard changes. In 2003/2004 the within-model prices of Groups 1, 3 and 4 were trending downward most quickly overall, however, in 2006/2007 this downward within-model price trend was concentrated in the highest efficiency groups (1 and 2). There were no statistically significant breaks in trend following the 2004 standard change in any groups. However, following the 2007 standard change, the within-model price trends of the two most efficient groups (1 and 2), already trending downward at the highest rate, experienced additional significant downward breaks in trend.

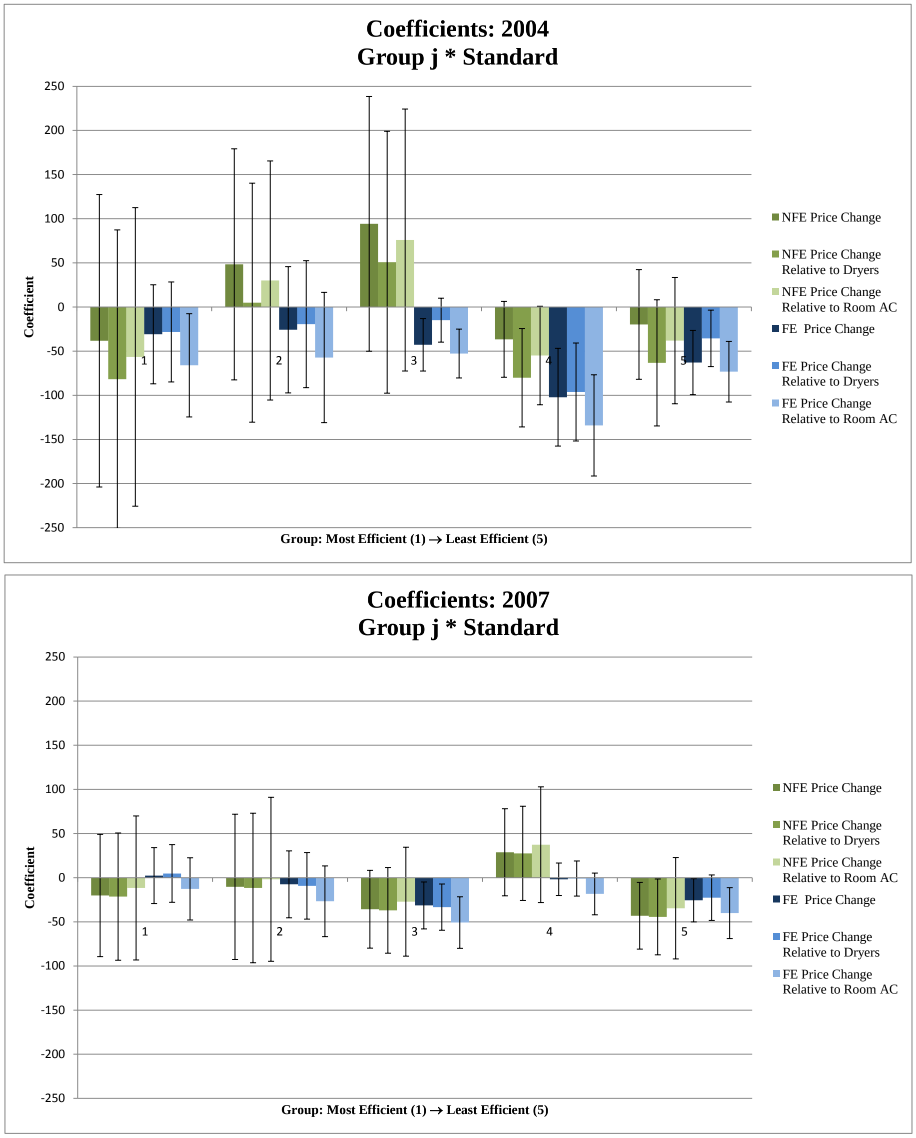
The trend effects – limited to the within-model effects – across the groups are presented in Figure 6, which presents the combined within-model trend terms (i.e. the sum of the coefficient on $Group_{ji} * Trend_t$ and on $Standard_t * Group_{ji} * Trend_t$). Figure 6 makes clear that the within-model prices of the highest efficiency groups were trending down most quickly at the time of both standard changes. These results are consistent with a pattern of newer/more efficient models being priced at a higher level initially, and dropping in price more quickly relative to older/less efficient models. This could be due to strategic intertemporal price discrimination strategies by firms, "learning-by-doing" reductions in production costs, or both.

I now relate these results explicitly to the predictions of the model presented in Section 2. Recall price discrimination predicted that the models decertified from ENERGY STAR should see an immediate price drop, and models that are close substitutes to those for which the minimum standard is binding should see an immediate price decrease (i.e. the lower efficiency categories). This is in contrast to the perfectly competitive model, in which the lower efficiency segments of the market should see an increase in price, or at least no decrease.

Looking first at the top panel of Figure 5 summarizing the price level effects for the 2004 standard change, you can see that Group 4 and Group 5 – the two least efficient groups – saw a significant and robust price drop, which is inconsistent with a perfectly competitive model, but consistent with the model which allows for price discrimination. Additionally, this price drop is seen for Group 3 when looking at the within-model price change, though not for the average price specifications. The predictions of the model allow for an ambiguous effect around the middle and high-end of the market, which is what we see here. If any models were decertified from ENERGY STAR in 2004, we should see a price drop at the mid-high end of the market, which we do see to a certain extent in the within-model price change for Group 3, though this does not seem to be an obvious effect. In sum, the level drop in prices appears to be driven by the low end of the market in 2004, providing support for the price discrimination hypothesis.

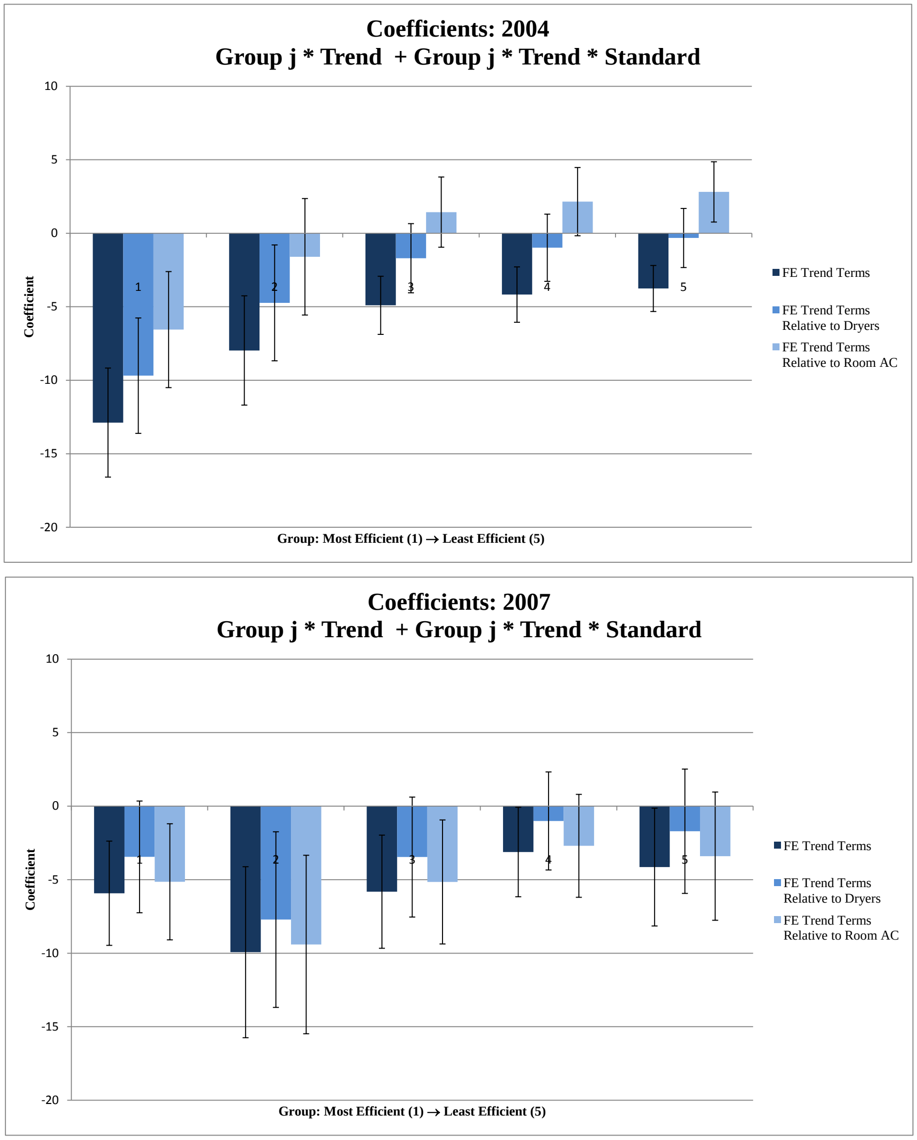
Turning now to the price level effects from 2007 presented in the bottom panel of Figure 5, we see the same pattern as for 2004, but with smaller magnitudes. In particular, for Groups 5 and 3 we see significant price drops, particular within-model, with no consistent effects for the other groups. Once again, this price drop for the lowest efficiency group is inconsistent with the perfectly competitive model, but consistent with the predictions of the price-discrimination model.

Figure 5: Coefficients from Efficiency-Level Regressions: Level Effect



Note: Coefficients from regressions presented in Tables 7 and 8. The top panel shows the level-effect of the standard on prices across the five efficiency categories for the 2004 standard, and the bottom panel shows the same results for the 2007 standard. The 95% confidence interval is shown for each coefficient.

Figure 6: Coefficients from Efficiency-Level Regressions: Within-Model Trends

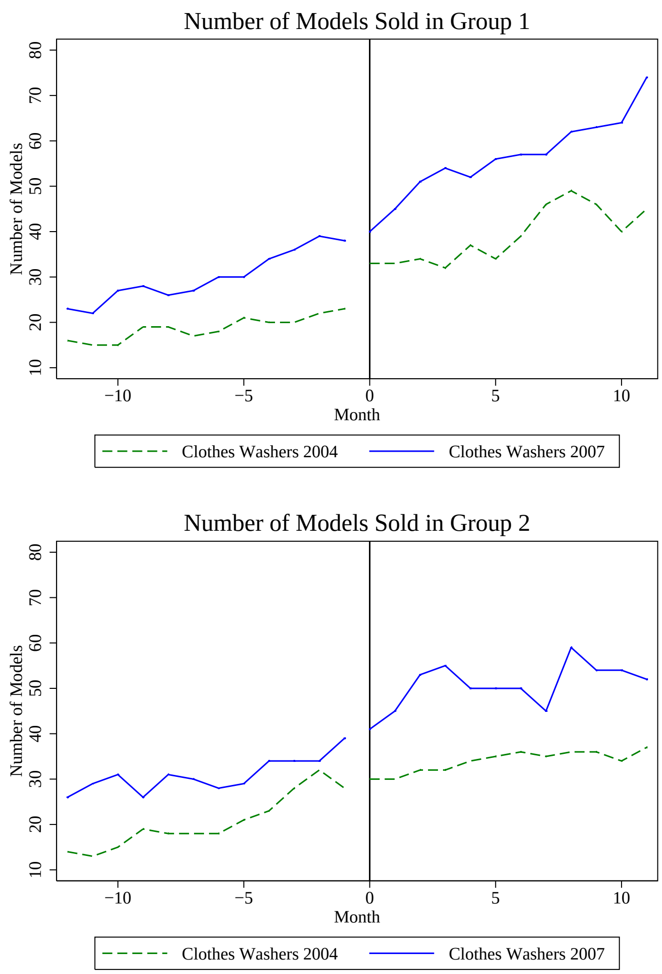


Note: Sum of trend coefficients from regressions presented in Table 8. The top panel shows the within-model price trends across the five efficiency categories at the 2004 standard, and the bottom panel shows the same results for the 2007 standard. The bars are the sum of the coefficients on $Group_{ji} * Trend_t$ and $Standard_t * Group_{ji} * Trend_t$. The 95% confidence interval for this combined term is shown.

4.3 Testing Model Prediction: Menu Adjustment

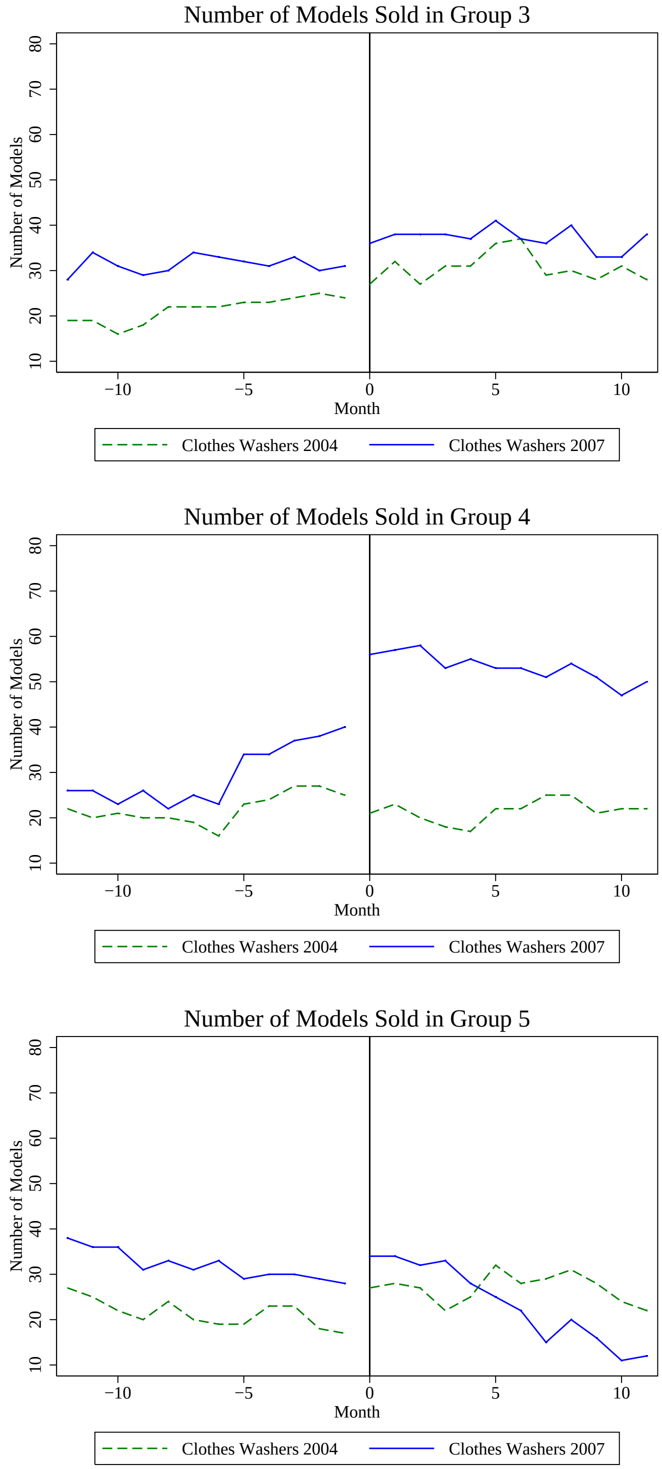
The second prediction of the imperfect competition model is that firms will spread efficiency upwards to alleviate price competition across the market after the new standard restricts the efficiency distribution. Figures 7 and 8 demonstrates evidence of this pattern, showing the total number of individual models offered in each efficiency group around the standard change dates. In particular, the lowest efficiency group (5) sees a drop-off in the number of models available in the market, particularly following the 2007 standard. This is what we'd expect given the standard will cause some models to exit the market as they no longer meet the minimum requirement of the standard. More interestingly, we see a distinct increase in the number of models offered in the highest efficiency group (1). This is consistent with firms spreading efficiency upward to alleviate the increased price competition across their products as a result of the standard.

Figure 7: Proliferation of New Models in Market by Efficiency Category (Groups 1 and 2)



Note: Total number of individual model numbers within each efficiency category that were sold in each time period for the year just prior to, and the year just following, each new standard.

Figure 8: Proliferation of New Models in Market by Efficiency Category (Groups 3, 4 & 5)



Note: Total number of individual model numbers within each efficiency category that were sold in each time period for the year just prior to, and the year just following, each new standard.

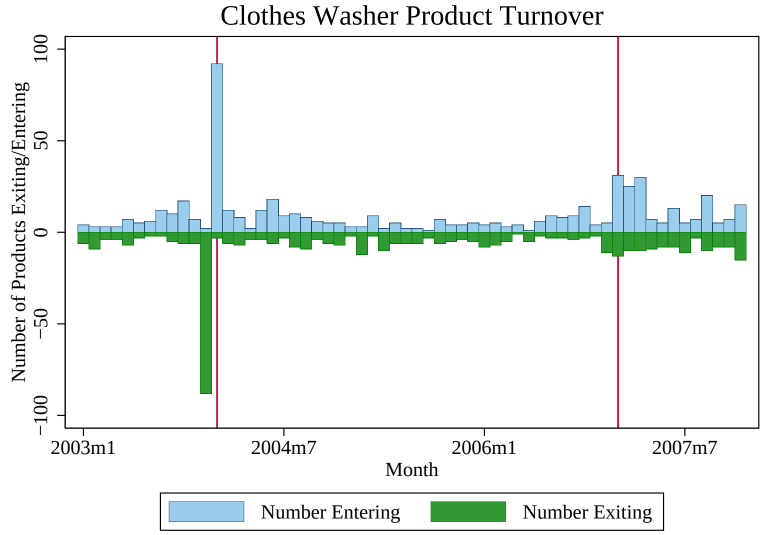
4.4 Firm Response Strategies in 2004 versus 2007

The results from Section 4.2, while indicating prices tend to be depressed following the standard changes – and drop discontinuously to the largest extent for the lowest efficiency groups – do indicate differences between the standard change in 2004 versus 2007. One would expect that firms might respond differently to these two standard changes for several reasons. First, both standards were adopted in 2001 as part of the same standard rule-making. Therefore, it stands to reason firms had more time to adapt to the 2007 standard than to the 2004 standard. Also, the previous standard affecting the clothes washer market prior to 2004 was effective in 1994, meaning that at the time the standard changed in 2004, 10 years had elapsed since the last tightening of the minimum efficiency standard. One might expect, therefore, that adaptation strategies might be relatively prevalent or inexpensive in 2004, whereas three years later in 2007, the inexpensive options had already been exhausted and so other strategies were likely implemented. This section explores the differences in the apparent strategies used to adapt to these two standards, and relates these differences to the differences in price effects across the efficiency groups presented in Section 4.2.

Figure 9 depicts the frequency of individual model numbers entering and exiting the market at each month in the study period. A model number is said to exit the market in month t if the last observation of that model occurs in month t. Similarly a model is said to enter the market in month t if the first time that model appears in the data is in month t. It is immediately apparent looking at this figure that close to 100 models exited the market in December 2003 (well over half the models in the market), and close to 100 entered in January 2004. However, the vast majority of models exiting the market in December 2003 have the same model number, except one or two characters, as models entering in December 2004, while the energy use level of these matched-pairs drops. For example, Whirlpool model GHW9250M exited the market in December 2003, having an FTC rating of 294 kWh/year, while Whirlpool model GHW9250ML entered the market in January 2004, having an FTC rating of 285 kWh/year. This pattern is not observed to nearly the same extent at the 2007 standard change. This indicates firms likely made small internal adjustments to existing models in order to come into compliance with the new standard in 2004. These inexpensive changes were likely exhausted by the time the 2007 standard came along, however, requiring that firms respond by eliminating more low-end models, rather than bringing them into compliance.[10]

[10] Appendix 5 provides a figure that shows the same frequency of models entering and exiting, but does so specifically within each efficiency group. It is clear that the models being adapted and swapped-out in 2004 were not only models at the low end of the efficiency spectrum. This indicates that models were likely being adapted not only to meet the new minimum standard, but that mid-range products that had been ENERGY STAR before the standard were adapted to meet the new ENERGY STAR standard as well. Therefore, it is possible that few models were disqualified from ENERGY STAR in 2004.

Figure 9: Model Entry and Exit From Market by Date



Note: Frequency of models entering and exiting the data in each month in the sample for years 2003 through 2007. The occurrences of the combined change in minimum and ENERGY STAR standards are indicated by the vertical lines. The upward-facing histogram indicates frequency of new models entering the data, while the downward-facing histogram indicates frequency of models exiting the data.

How do these results relate to the results presented in Section 4.2 and 4.3? First, prior to 2004 it is reasonable to assume that firms had been engaging in more or less their optimal pricing strategy given market conditions. If they were price discriminating, they were under-providing efficiency to the customers with the lowest willingness to pay, and charging positive margins on all products in the market. Additionally, these positive margins increased in magnitude moving up the efficiency spectrum. Then the 2004 standard was imposed, which forced them to increase the efficiency level of the lowest type of products, eliminating that essential lever that had allowed them to charge high margins on higher efficiency products. This forced them to drop the prices of products that were close substitutes to those eliminated by the standard (Groups 3, 4 and 5), which we see in the regression results and is predicted by the price discrimination model. Then, at the time the 2007 standard came into effect, margins were already depressed from the relatively recent 2004 standard, and inexpensive adaptation strategies had already been exhausted. For this reason the price drops in the lowest efficiency categories are of a lower magnitude relative to the drops seen in 2004. In both cases the range of efficiency is restricted by the standard and firms respond by spreading efficiency upward to alleviate competition across the spectrum of their products. However, we see products dropping out of the lowest efficiency group and proliferating in the highest efficiency group more so in 2007 than 2004, which corroborates the theory that firms were modifying existing models to meet the new standards more in 2004, while dropping and introducing completely new models more in 2007.

5 Conclusion

Beginning in 1987, the United States federal government has set minimum energy efficiency standards for more than 55 products. Some have questioned the justifiability of minimum efficiency standards for appliances as implemented by the DOE. For example, Gayer and Viscusi (2012) make the following argument:

> The impetus for the new wave of energy efficiency regulations has little to do with externalities. Instead, the regulations are based on an assumption that government choices better reflect the preferences of consumers and firms than the choices consumers and firms would make themselves. In the absence of these claimed private benefits of the regulation, the costs to society dwarf the estimated benefit.

They argue that if the purchase of a more efficient appliance resulted in a net benefit to consumers, they would already have made the purchase, ergo the imposition of a standard eliminating certain models from the market must result in a net welfare loss. Much of the literature discussing the "Energy Efficiency Gap,"[11] and the accompanying justification for minimum efficiency standards, suggests that consumers have some form of bounded rationality (they do not pay attention to, or hyperbolically discount, future savings in operating costs from a more efficient product). While evidence exists that consumers do exhibit these types of preferences/behaviors,[12] Gayer and Viscusi (2012) among others believe the idea that the government "knows better" than consumers is an unjustified paternalistic attitude. However, the argument Gayer and Viscusi (2012) make against minimum efficiency standards assumes appliance markets are perfectly competitive. In a perfectly competitive market, setting aside any question of environmental externalities, everyone has full information, no single firm can strategically influence the market price, and the equilibrium – absent any policy intervention – maximizes social welfare. If, however, the market is not perfectly competitive, but rather consists of firms with the capability to price discriminate, then a minimum efficiency standard directly addresses this market failure.

I have presented a model of second-degree price discrimination in a quality-differentiated market for household durables based on the classic work by Mussa and Rosen (1978), as well as Ronnen (1991), De Meza and Ungern-Sternberg (1982), Katz (1984), and Crampes and Hollander (1995). I have adapted this model to the Unites States clothes washer market, and extended the model to allow for a change in the ENERGY STAR standard concurrent to the change in minimum efficiency standard. This market has a high degree of market concentration with one firm, Whirlpool, holding close to 60% of the market share according to the data used in this analysis. Assuming consumers have heterogeneous preferences for energy efficiency (possibly due to heterogeneous discount rates or environmental attitudes), firms with market power have an incentive to under-provide efficiency at the low end of the market, allowing them to charge positive and increasing margins on all other efficiency levels moving up the efficiency distribution of products. Imposing a minimum efficiency

[11] The term "Energy Efficiency Gap" is used to describe the observation that consumers apparently are not purchasing products that have a positive NPV.

[12] An excellent summary of the empirical evidence of several types of non-standard preferences can be found in DellaVigna (2009).

standard in this setting forces price-discriminating firms to drop prices, particularly of the lowest efficiency categories just above those eliminated by the new standard. In a perfectly competitive market on the other hand, one would expect prices of the lowest efficiency categories to increase.

I find evidence of an average drop in the prices of clothes washers at the times of the standard changes. Both in 2004 and 2007, prices dropped predominantly within-model, although the overall price distribution did not appear to significantly change at either standard change date.

In addition, I show that at both standard changes, the prices of the three lowest efficiency groups dropped the most. This result is inconsistent with a perfectly competitive market, while explicitly predicted by an imperfectly competitive market in which firms have been engaged in second-degree price discrimination.

I show evidence that along with a level drop in prices at the time the new standards went into effect, price trends broke downward, particularly following the 2007 standard change. The within-model downward trend in prices was particularly pronounced in the higher efficiency categories. This is consistent with the idea that firms experience some "learning-by-doing" in the production process when new technologies or innovations are introduced in the market. It is also consistent with firms engaged in intertemporal price discrimination.

I show, as well, evidence of an increased proliferation of new models in the highest efficiency range of products following both standard changes. This is consistent with firms attempting to spread the efficiency distribution upwards following the restriction imposed by the new standard. Ronnen (1991) and Crampes and Hollander (1995) predict this behavior, which is the result of firms attempting to alleviate price competition across the efficiency spectrum.

Additionally, I provide evidence that firms adapted many models to meet the 2004 standard, rather than eliminating them from the market. I do not see this pattern to the same extent in 2007.

Prices dropped by a smaller magnitude at the time of the 2007 standard change, relative to the 2004 standard change. This is consistent with margins having already been reduced for these groups at the standard change in 2004, leaving less room to drop prices when the standard changed in 2007. This last point is important from a policy perspective, as there is some debate about how frequently standards should be imposed. Indeed, results from Chen, Dale and Roberts (2013) and those presented here, indicating that standards tend to have a negative effect on prices, could lead some to push for more frequent standard changes. However, looking at the difference in magnitudes of the price drops in 2004 relative to 2007 should introduce a note of caution into the debate. Prices can only decrease so far before margins have no further room to drop. More frequent standards might lead to price increases, even if firms still hold power in the market, but do not have time to adapt technology, product menu, and prices following one standard before another is imposed.

This analysis provides direct evidence that the market for clothes washers is not perfectly competitive and that firms in this market have historically engaged in second-degree price discrimination. Therefore, quite aside from arguments about the role of government in rectifying the apparent "Energy Efficiency Gap," which have been seen as paternalistic at best by some, this paper demonstrates that minimum efficiency standards are justified, and indeed desirable, from a classic economic perspective, as standards directly address the imperfect competition market failure in this quality-differentiated market.

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Appendix 1: Detailed Derivation of Model with Three Consumer Types

Assume consumers have unit demand for a good. Assume there are multiple models of clothes washers provided by the monopolist, indexed by j, which vary over efficiency level (e_j) and price (p_j). Assume there are three types of consumers – high 1, middle 2, and low 3 – that have a high, mid-range, and low willingness to pay for efficiency, respectively; assume θ^k is the valuation of consumer type k for efficiency e_j of model j where, without loss of generality, $\theta^3 < \theta^2 < \theta^1$. Utility of consumer i for model j is:

$$
\begin{aligned}
U_{kj} &= \theta^k e_j - p_j \\
&\text{where:} \\
\theta^k \in \{\theta^3, \theta^2, \theta^1\} &= \text{valuation of energy efficiency } e \text{ of the three consumer types} \\
e_j &= \text{energy efficiency level of model } j \\
p_j &= \text{purchase price of model } j
\end{aligned}
$$

Suppose there are N consumers and $s_3 N$ have valuation θ^3, $s_2 N$ have valuation θ^2, and $s_1 N$ have valuation θ^1, where $\sum_{k=1}^{3} s_k = 1$. 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 $c(e_j)$, and that $c(e_j) \geq 0$, $c'(e_j) \geq 0$ and $c''(e_j) > 0$.

Social Welfare Maximizing (Perfectly Competitive) Case:

A social planner would choose the efficiency levels to maximize total welfare (averaged over the population with weights based on the distribution of types in the population). They would therefore solve the optimization problem presented in Equation 10.

$$
\max_{e_1, e_2, e_3} W = s_3 \cdot \Big(\theta^3 e_3 - c(e_3)\Big) + s_2 \cdot \Big(\theta^2 e_2 - c(e_2)\Big) + s_1 \cdot \Big(\theta^1 e_1 - c(e_1)\Big) \tag{10}
$$

The first order conditions for the social planner are shown in Equation System 11.

$$
\begin{aligned}
c'(e_3^*) &= \theta^3 \\
c'(e_2^*) &= \theta^2 \\
c'(e_1^*) &= \theta^1
\end{aligned} \tag{11}
$$

While in this case consumer demand is perfectly inelastic, in a perfectly competitive setting with free entry of firms, price above marginal cost would result in excess supply. Therefore the optimal prices are also equal to marginal cost for the social welfare maximizing case. This result is shown in Equation System 12.

$$
\begin{aligned}
c'(e_3^*) &= p^{3*} \\
c'(e_2^*) &= p^{2*} \\
c'(e_1^*) &= p^{1*}
\end{aligned} \tag{12}
$$

Monopolist Second-Degree Price Discrimination Case:

The monopolist solves the problem in Equation 13 in order to choose the efficiency levels and prices of the three types of models they supply. The $IR1$, $IR2$ and $IR3$ constraints refer to the IR constraint for the high, middle, and low type of consumer, respectively. The ICj_k constraint refer to the constraint assuring that consumer type j will be unwilling to purchase product type $k \neq j$ in equilibrium.

$$\begin{aligned}
\max_{p_1,p_2,p_3,e_1,e_2,e_3} \; & \pi = s_3 \cdot (p_3 - c\,(e_3)) + s_2 \cdot (p_2 - c\,(e_2)) + s_1 \cdot (p_1 - c(e_1)) \\
s.t. & \\
IR1 : & \theta^1 e_1 - p_1 \geq 0 \\
IR2 : & \theta^2 e_2 - p_2 \geq 0 \\
IR3 : & \theta^3 e_3 - p_3 \geq 0 \\
IC1_2 : & \theta^1 e_1 - p_1 \geq \theta^1 e_2 - p_2 \\
IC1_3 : & \theta^1 e_1 - p_1 \geq \theta^1 e_3 - p_3 \\
IC2_1 : & \theta^2 e_2 - p_2 \geq \theta^2 e_1 - p_1 \\
IC2_3 : & \theta^2 e_2 - p_2 \geq \theta^2 e_3 - p_3 \\
IC3_1 : & \theta^3 e_3 - p_3 \geq \theta^3 e_1 - p_1 \\
IC3_2 : & \theta^3 e_3 - p_3 \geq \theta^3 e_2 - p_2
\end{aligned} \tag{13}$$

In a separating equilibrium (i.e. $p_j \neq p_k$ and $e_j \neq e_k \; \forall j \neq k$) then $\theta^1 > \theta^2 > \theta^3$ implies that $IR3$, $IC1_2$ and $IC2_3$ are binding while $IR1$, $IR2$ $IC1_3$, $IC2_1$, $IC3_1$ and $IC3_2$ are all non-binding.[13] Therefore the original problem from Equation 13 simplifies to the problem in Equation 14.

$$\begin{aligned}
\max_{p_1,p_2,p_3,e_1,e_2,e_3} \; & \pi = s_3 \cdot (p_3 - c\,(e_3)) + s_2 \cdot (p_2 - c\,(e_2)) + s_1 \cdot (p_1 - c(e_1)) \\
s.t. & \\
IR3 : & \theta^3 e_3 - p_3 = 0 \\
IC1_2 : & \theta^1 e_1 - p_1 = \theta^1 e_2 - p_2 \\
IC2_3 : & \theta^2 e_2 - p_2 = \theta^2 e_3 - p_3
\end{aligned} \tag{14}$$

Solving for p_1, p_2 and p_3 from the constraints and plugging back into the objective function, the problem simplifies further to that in Equation 15.

$$\begin{aligned}
\max_{e_1,e_2,e_3} \pi = & s_3 \cdot \Big(\theta^3 e_3 - c\,(e_3)\Big) \\
& + s_2 \cdot \Big(\theta^2\,(e_2 - e_3) + \theta^3 e_3 - c\,(e_2)\Big) \\
& + s_1 \cdot \Big(\theta^1\,(e_1 - e_2) + \theta^2\,(e_2 - e_3) + \theta^3 e_3 - c(e_1)\Big)
\end{aligned} \tag{15}$$

[13] I provide the proof of this in Appendix B.2.

The first order conditions to this problem are shown in Equation System 16.

$$\begin{aligned} s_3 \cdot \left(\theta^3 - c'\left(e_3\right)\right) - s_2 \cdot \left(\theta^2 - \theta^3\right) - s_1 \cdot \left(\theta^2 - \theta^3\right) = 0 \\ s_2 \cdot \left(\theta^2 - c'\left(e_2\right)\right) - s_1 \cdot \left(\theta^1 - \theta^2\right) = 0 \\ s_1 \cdot \left(\theta^1 - c'(e_1)\right) = 0 \end{aligned} \tag{16}$$

Using these first order conditions and the binding constraints, the solution for the monopolist under this second-degree price discrimination setting $\left(\bar{e}_j, \bar{p}_j\right), \ \forall j \in \{1,2,3\}$ are presented in Equation System 17.

$$\begin{aligned} c'(\bar{e}_3) =& \theta^3 - \frac{s_1 + s_2}{s_3}\left(\theta^2 - \theta^3\right) \\ c'\left(\bar{e}_2\right) =& \theta^2 - \frac{s_1}{s_2}\left(\theta^1 - \theta^2\right) \\ c'(\bar{e}_1) =& \theta^1 \\ \bar{p}_3 =& \theta^3 \bar{e}_3 \\ \bar{p}_2 =& \theta^3 \bar{e}_3 + \theta^2\left(\bar{e}_2 - \bar{e}_3\right) \\ \bar{p}_H =& \theta^3 \bar{e}_3 + \theta^2\left(\bar{e}_2 - \bar{e}_3\right) + \theta^1\left(\bar{e}_1 - \bar{e}_2\right) \end{aligned} \tag{17}$$

Monopoly Second-Degree Price Discrimination with Minimum Standard Case:

The new problem with the constraint that $e_j \geq e_3^*, \ \forall j \in \{1,2,3\}$, where this constraint is binding for type 3 products is presented in Equation 18.

$$\begin{aligned} \max_{p_1,p_2,p_3,e_1,e_2,e_3} \pi = s_3 \cdot \left(p_3 - c\left(e_3\right)\right) + s_2 \cdot \left(p_2 - c\left(e_2\right)\right) + s_1 \cdot \left(p_1 - c(e_1)\right) \\ s.t. \\ IR3 : \theta^3 e_3 - p_3 = 0 \\ IC1_2 : \theta^1 e_1 - p_1 = \theta^1 e_2 - p_2 \\ IC2_3 : \theta^2 e_2 - p_2 = \theta^2 e_3 - p_3 \\ Standard : e_3 = e_3^* \end{aligned} \tag{18}$$

Simplifying the problem further by plugging in the constraints, I get Equations 19.

$$\begin{aligned} \max_{e_2,e_1} \pi =& s_3 \cdot \left(\theta^3 e_3^* - c\left(e_3^*\right)\right) \\ &+ s_2 \cdot \left(\theta^2\left(e_2 - e_3^*\right) + \theta^3 e_3^* - c\left(e_2\right)\right) \\ &+ s_1 \cdot \left(\theta^1\left(e_1 - e_2\right) + \theta^2\left(e_2 - e_3^*\right) + \theta^3 e_3^* - c(e_1)\right) \end{aligned} \tag{19}$$

The first order conditions are shown in Equation System 20.

$$s_2 \cdot \left(\theta^2 - c'\left(e_2\right)\right) - s_1 \cdot \left(\theta^1 - \theta^2\right) = 0 \tag{20}$$
$$s_1 \cdot \left(\theta^1 - c'(e_1)\right) = 0$$

Using these conditions and the rest of the binding constraints I can solve for the new monopoly menu of optimal price and efficiency levels given the standard, presented in Equation System 21.

$$\begin{aligned} c'(e_3^S) &= c'(e_3^*) = \theta^3 \\ c'\left(e_2^S\right) &= \theta^2 - \frac{s_1}{s_2}\left(\theta^1 - \theta^2\right) \\ c'(e_1^S) &= \theta^1 \\ p_3^S &= \theta^3 e_3^* \\ p_2^S &= \theta^3 e_3^* + \theta^2\left(e_2^S - e_3^*\right) \\ p_1^S &= \theta^3 e_3^* + \theta^2\left(e_2^S - e_3^*\right) + \theta^1\left(e_1^S - e_2^S\right) \end{aligned} \tag{21}$$

Appendix 2: Binding Constraints in Price Discrimination Model

Proposition: In a separating equilibrium then $\theta^1 > \theta^2 > \theta^3$ implies that $IR3$, $IC1_2$ and $IC2_3$ are binding while $IR1$, $IR2$ $IC1_3$, $IC2_1$, $IC3_1$ and $IC3_2$ are all non-binding.

Proof:

1. ICj_k and ICk_j cannot both be binding $\forall j \neq k$ and $j, k \in \{1, 2, 3\}$:

   ICj_k and ICk_jboth binding

   By contradiction:

   $\theta^k e_k - p_k = \theta^k e_j - p_j$

   and $\theta^j e_j - p_j = \theta^j e_k - p_k$

   $\Rightarrow \theta^k = \frac{p_k - p_j}{(e_k - e_j)}$ (ok because assume $e_k \neq e_j$)

   and $\theta^j = \frac{p_k - p_j}{(e_k - e_j)}$

   $\Rightarrow \theta^k = \theta^j \boxtimes$

   Violates assumption that $\theta^k \neq \theta^j$, therefore ICj_k and ICk_j cannot both be binding.

2. If IRk is satisfied in equilibrium, then IRj $\forall j > k$ are satisfied in equilibrium.

   Directly: Assume IRk is satisfied

   $\theta^k e_k - p_k \geq 0$, and e_k and p_k are a feasible efficiency/price combination for the monopolist

   $\theta^j > \theta^k$ by assumption

   $\Rightarrow \theta^j e_k - p_k > 0$

   $\Rightarrow \exists (e_j, p_j) = (e_k, p_k)$ that is feasible for the monopolist, and $\theta^j e_j - p_j > 0$

   $\Rightarrow IRj$ is satisfied $\boxdot$

3. $IR3$ is binding

   By (2), if there is a type such that $\theta^j e_j - p_j \geq 0$ for that type j, then all higher types will thereby satisfy their IR constraints. The monopolist's profits are increasing in price and decreasing in efficiency level. They have an incentive to set price as high as possible and efficiency as low as possible. They will therefore set price and efficiency for this lowest feasible type j just such their IR constraint holds. Without loss of generality, call this lowest feasible type 3. Therefore $IR3$ is binding.

4. $IR2$ and $IR1$ are non-binding

   (a) By (3) $IR3$ is binding $\Rightarrow \theta^3 e_3 - p_3 = 0$

$IR1$ is non-binding:

$\theta^1 e_3 - p_3 > \theta^3 e_3 - p_3$ by $\theta^1 > \theta^3$

$IC1_3$ assures that: $\theta^1 e_1 - p_1 \geq \theta^1 e_3 - p_3$

$\Rightarrow \theta^1 e_1 - p_1 > 0$

$\Rightarrow IR1$ is non-binding

$IR_2$is non-binding:

Same proof as for $IR1$.

5. Either $IC1_3$ or $IC1_2$ is binding, and either $IC2_1$ or $IC2_3$ are binding.

   Either $IC1_3$ or $IC1_2$ is binding:

   By contradiction:

   From (4) $IR1$ is non-binding. If $IC1_3$ or $IC1_2$ are both non-binding as well, then $\theta^1 e_1 > p_1$ and $\theta^1 e_1 - \theta^1 e_3 + p_3 > p_1$ and $\theta^1 e_1 - \theta^1 e_2 + p_2 > p_1$ and $\exists \varepsilon$ s.t. $\theta^1 e_1 > p_1 + \varepsilon$ and $\theta^1 e_1 - \theta^1 e_3 + p_3 > p_1 + \varepsilon$ and $\theta^1 e_1 - \theta^1 e_2 + p_2 > p_1 + \varepsilon$. Then the monopoly could raise p_1 by ε (thereby increasing their profit) and have type θ^1 still be willing to be in the market and still purchase the type 1 product over the type 2 or 3 products, so the original p_1 can't have been an equilibrium price. ⊠

   Either $IC2_1$ or $IC2_3$ are binding: Same proof as for $IC1_3$ or $IC1_2$.

6. $IC1_3$ is non-binding:

   By contradiction:

   If not, then $\theta^1 e_1 - p_1 = \theta^1 e_3 - p_3$.

   $IC1_2$ assures us that $\theta^1 e_1 - p_1 \geq \theta^1 e_2 - p_2$

   Subtract $\theta^1 e_1 - p_1$ from the left-hand side of $IC1_2$ and subtract $\theta^1 e_3 - p_3$ from the right-hand side of $IC1_2$:

   $\Rightarrow 0 \geq \theta^1 (e_2 - e_3) - (p_2 - p_3)$

   $\Rightarrow \frac{(p_2 - p_3)}{(e_2 - e_3)} \geq \theta^1$ (taking as given that $e_2 > e_3$, which is the case in the solution to the problem).

   $\Rightarrow \frac{(p_2 - p_3)}{(e_2 - e_3)} > \theta^2$ by $\theta^1 > \theta^2$

   $\Rightarrow \theta^2 e_2 - p_2 < \theta^2 e_3 - p_3$ ⊠

   This contradicts the assumption that the $IC2_3$ must be satisfied. Therefore, $IC1_3$ is non-binding.

7. $IC1_2$ is binding

   By (4), (5) and (6)

8. $IC2_1$ is non-binding

   By (1) and (7)

9. $IC2_3$ is binding
   By (4), (5) and (8)
10. $IC3_2$ is non-binding
    by (1) and (9)

■

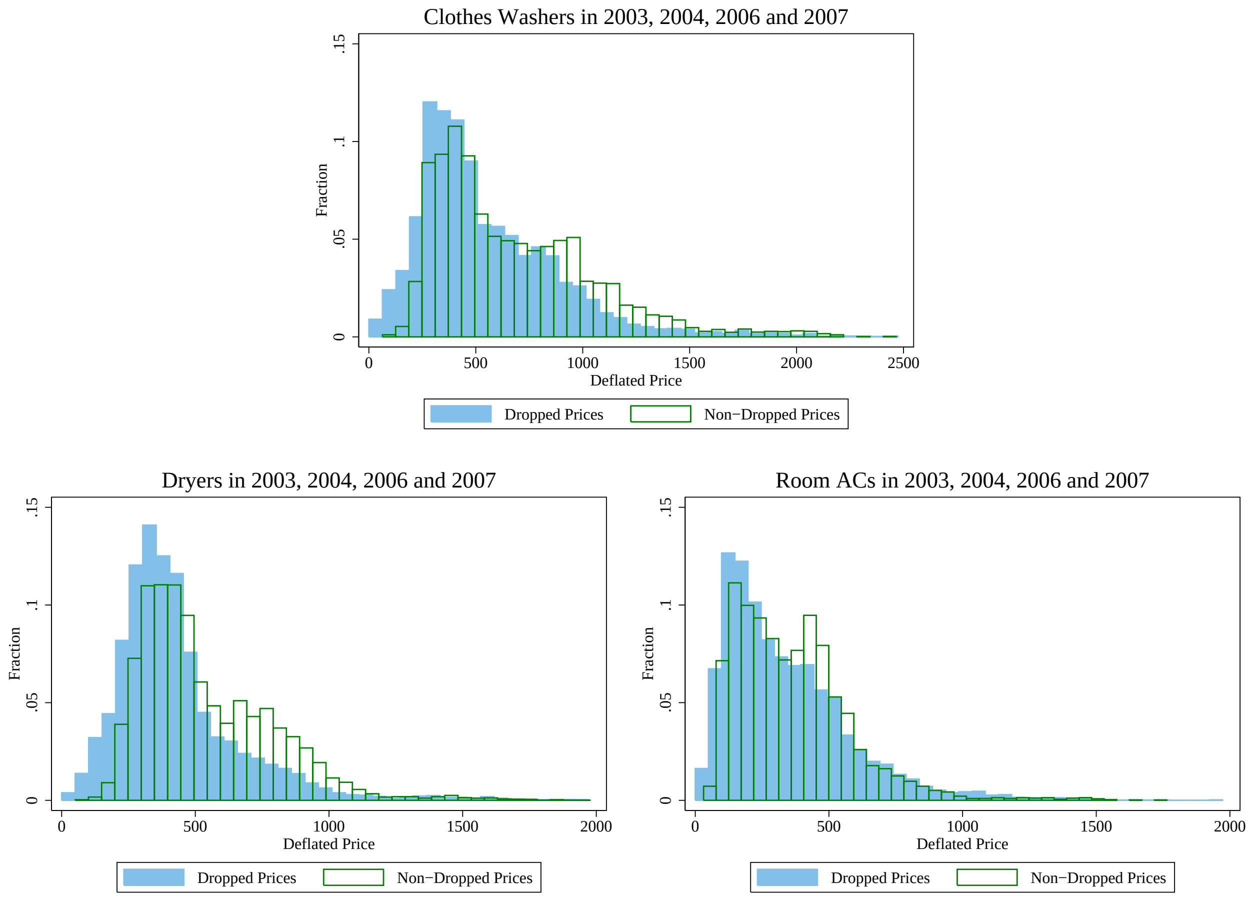
Appendix 3: Retailers in NPD Data

Participating Retailers in NPD data:		Projected* Sales Included for:
Abt TV & Appliance	Kmart	ABC Warehouse
Amazon.com	Kohl's	BrandsMart
American TV	Linens 'n Things (Data thru 12/08)	Conn's Appliance
Bernies	Lowe's	Cowboy Maloney's
Best Buy	Macy's	Fry's
BJ's Wholesale Club	Meijer	Home Depot
Bloomingdale's	Nebraska Furniture Mart	Menards
Boscov's	PC Richard & Sons	Navy Exchange
Circuit City (Data thru 2/09)	Pamida	Queen City Appliance
Dillard's	RC Willey	REX Stores
Fortunoff (Data thru 5/09)	Sears	Vann's
Fred Meyer	Shopko	
Gottschalks (Data thru 3/09)	Target	
HH Gregg	Ultimate Electronics	
JC Penney		

* "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.

Appendix 4: Comparison of Price Distributions of Included vs Omitted Data

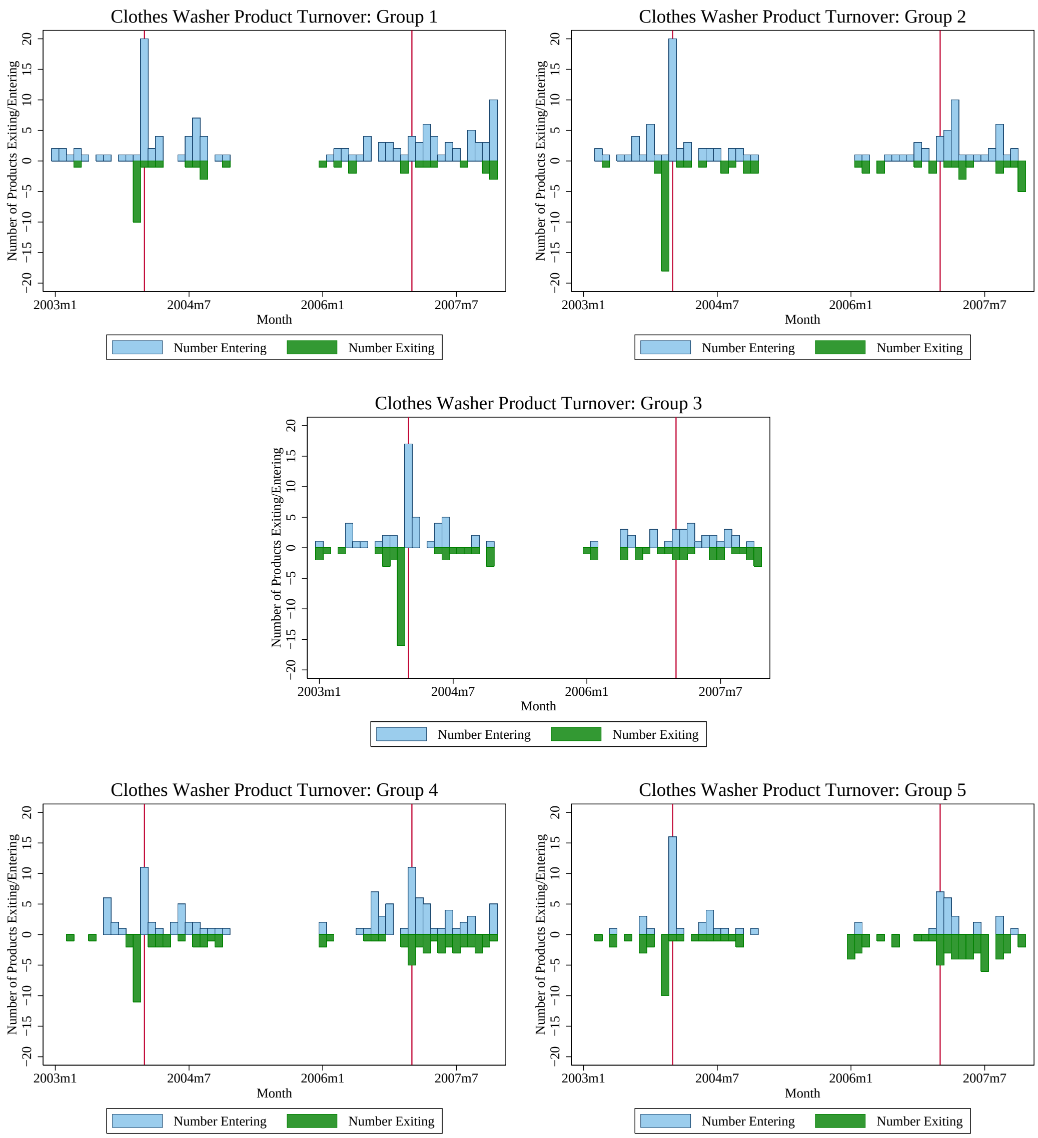
Figure 10: Price Distribution of Included vs Omitted Data



Note: Distribution of the price (average revenue deflated using the CPI with base period December 2009) of data used in the full analysis in this paper (outlined histogram) and data omitted from the analysis (solid histogram). The top panel shows this comparison for clothes washers, the middle panel for dryers, and the bottom panel for room ACs. The data was omitted for clothes washers because it consists of model numbers that could not be matched to FTC energy usage data because the model numbers were masked in the NPD data. Similarly masked model numbers were dropped from the data for dryers and room ACs as well to maintain comparability of the subset of data used for each appliance. A smaller subset of data was additionally dropped for clothes washers because the model numbers did not appear in the FTC energy efficiency data.

Appendix 5: Frequency of Models Exiting/Entering by Efficiency Group

Figure 11: Model Entry and Exit From Market by Date and Efficiency Category

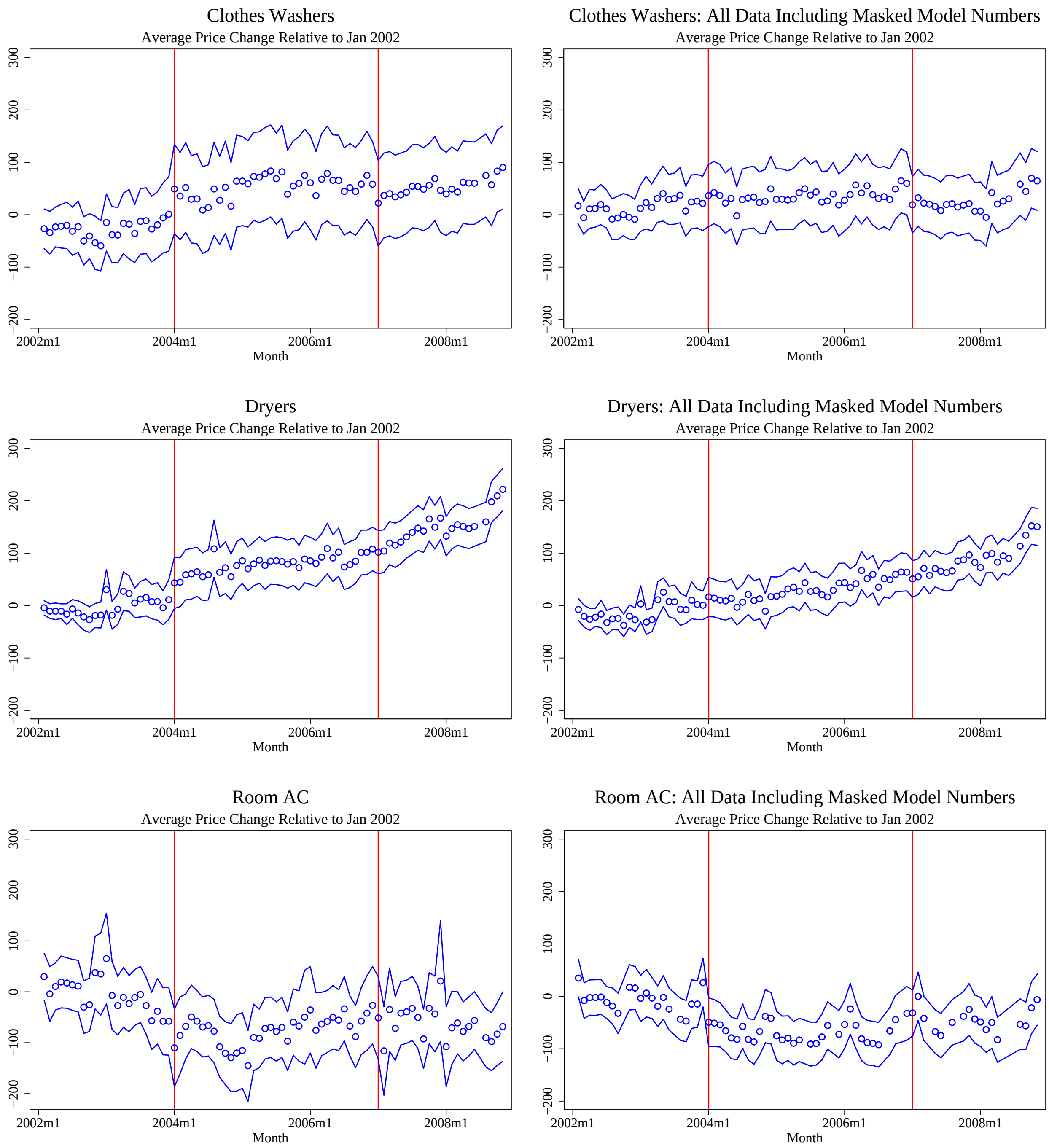


Note: Frequency of models entering and exiting the data within each efficiency category. The occurrences of the combined change in minimum and ENERGY STAR standards are indicated by the vertical lines. The upward-facing histogram indicates frequency of new models entering the data, while the downward-facing histogram indicates frequency of models exiting the data. The efficiency categorization was only done for the year just preceding and the year just following the occurrence of each standard.

Appendix 6: Robustness Check Including Otherwise Omitted Data

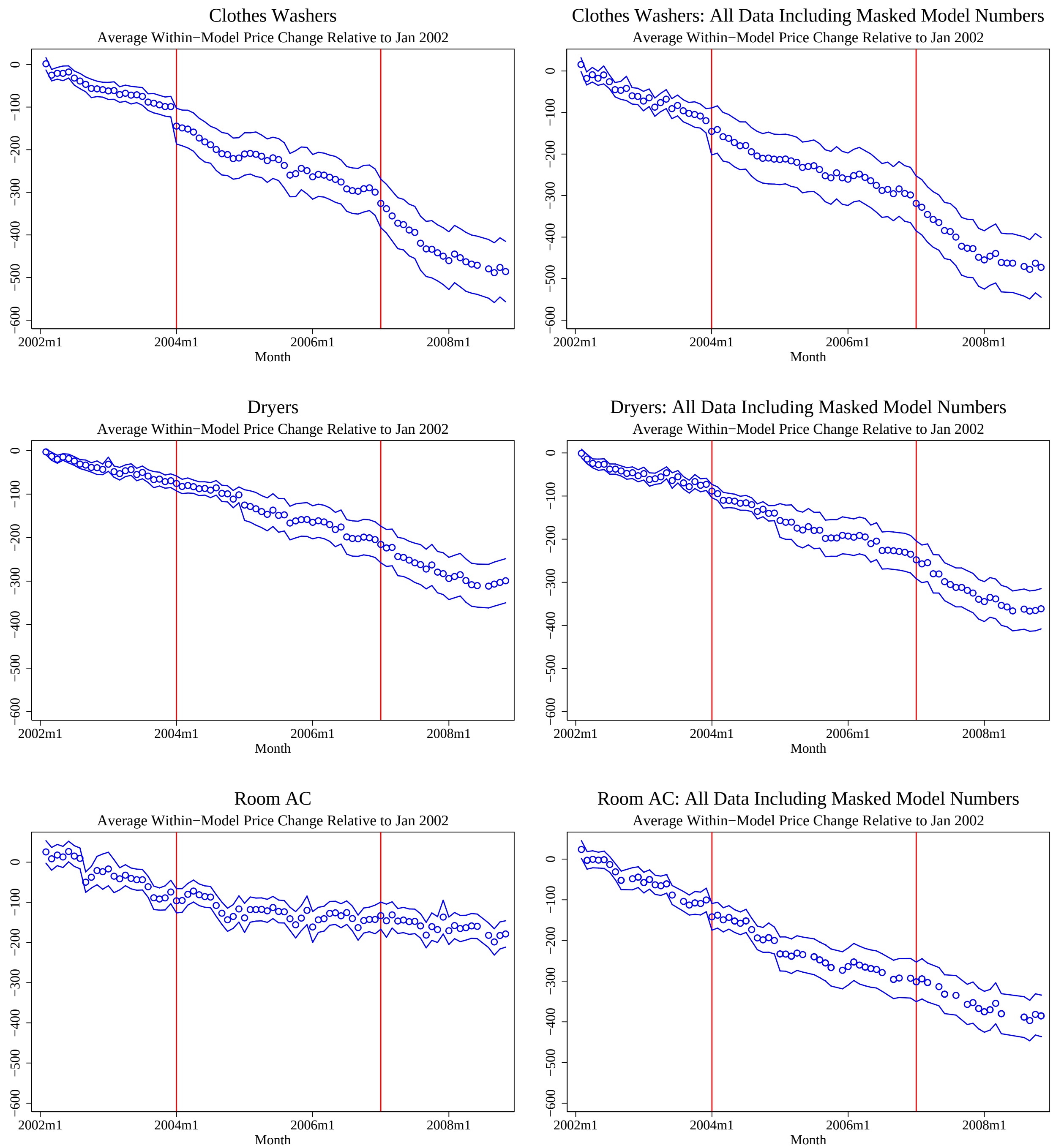
Because of the presence of masked model numbers, not all the data could be matched to the FTC kWh/year energy usage data. For this reason I chose to omit data that could not be matched to the FTC data throughout the primary analysis. However, there is concern that the omitted data is systematically different from the included data. The model numbers are masked because they would otherwise identify the retailer. A good example of products included in this category would be Kenmore products. The Kenmore brand is the Sears brand of products, and so products identifiable as Kenmore by their model number would therefore be identifiable as having been sold at Sears. Generally, Kenmore products are manufactured by the same set of manufacturers as products sold under other brands, and often are similar. For this reason, I am not overly concerned about the omitted data. However, to address potential bias introduced by omitting the masked model number data, I have done a series of robustness checks that I will present here. Namely, I have recreated the price trend figures, and the overall average regressions (not differentiated by energy usage level) with all the data. The price trend figures, comparing the original figures used in the body of the paper, and the figures with all data included, are presented in Figures 12 and 13. The regression results comparing the original results presented in the body of the paper, with the results when the regressions are run with all data included (not dropping the otherwise omitted observations) can be seen in Tables 9 and 10. Note that the regressions here which include fixed effects have to be interpreted cautiously. This is because many of the masked model numbers are aggregated together, therefore controlling for model-specific fixed effects does not actually control for individual models for some of these masked model numbers, but rather groups of models.

Figure 12: Market Average Price Trends with Omitted Data



Note: Market-average price trends for clothes washers (top row), dryers (middle row) and room ACs (bottom row) between 2002 and 2008. The left column shows the trends for the data used in the primary analysis and the right column shows the trends when all data is retained, including observations omitted from primary analysis. All prices are real (deflated using the CPI with December 2009 base-period), and are shown relative to the average price level in January 2002. The solid vertical lines show when the standard changed for clothes washers (January 2004 and January 2007).

Figure 13: Within-Model Price Trends with Omitted Data



Note: Market-average within-model price trends for clothes washers (top row), dryers (middle row) and room ACs (bottom row) between 2002 and 2008. The left column shows the trends for the data used in the primary analysis and the right column shows the trends when all data is retained, including observations omitted from primary analysis. All prices are real (deflated using the CPI with December 2009 base-period), and are shown relative to the average price level in January 2002. The solid vertical lines show when the standard changed for clothes washers (January 2004 and January 2007).

Table 9: Average Price Effect at New Standard Effective Dates with Omitted Data

	2004 Standard Change						2007 Standard Change					
	No Controls		Dryers as Controls		Room AC as Controls		No Controls		Dryers as Controls		Room AC as Controls	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dependent Var: Price	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data
T			146.7***	167.7***	185.8***	200.9***			161.9***	131.2***	345.9***	291.3***
			(34.94)	(24.44)	(36.50)	(24.70)			(35.93)	(23.24)	(35.96)	(22.17)
Trend			-0.418	1.145	-6.444***	-2.994**			1.219	1.756	0.434	-0.161
			(1.506)	(1.198)	(2.135)	(1.316)			(1.376)	(1.104)	(2.171)	(1.105)
Standard			43.47**	5.739	18.30	-21.42**			1.271	-10.36	-8.558	-0.498
			(18.11)	(12.73)	(18.15)	(10.76)			(10.46)	(9.378)	(22.03)	(11.47)
Trend * Standard			2.877	-1.683	0.295	-0.761			4.621**	1.564	1.850	3.083*
			(2.447)	(1.860)	(2.983)	(1.670)			(2.176)	(1.662)	(3.586)	(1.679)
T * Trend	2.043	0.214	2.461	-0.931	8.487**	3.208	0.103	1.466	-1.116	-0.290	-0.331	1.627
	(2.548)	(1.995)	(2.959)	(2.327)	(3.323)	(2.389)	(2.027)	(1.670)	(2.449)	(2.002)	(2.970)	(2.002)
T * Standard	40.83	3.747	-2.635	-1.992	22.54	25.17	-29.49*	-29.93*	-30.76	-19.57	-20.93	-29.44
	(35.64)	(26.28)	(39.96)	(29.20)	(39.98)	(28.39)	(16.66)	(15.45)	(19.66)	(18.07)	(27.62)	(19.24)
T * Trend * Standard	-1.872	-0.221	-4.749	1.462	-2.167	0.540	2.651	-2.398	-1.970	-3.962	0.801	-5.481*
	(4.010)	(3.009)	(4.696)	(3.537)	(4.997)	(3.441)	(2.885)	(2.246)	(3.612)	(2.794)	(4.602)	(2.804)
Constant	614.2***	610.4***	467.5***	442.7***	428.4***	409.5***	703.3***	622.6***	541.4***	491.4***	357.4***	331.4***
	(31.96)	(22.16)	(14.15)	(10.30)	(17.65)	(10.90)	(31.41)	(20.08)	(17.48)	(11.71)	(17.52)	(9.388)
Model Fixed Effects	N	N	N	N	N	N	N	N	N	N	N	N
Observations	3,637	6,562	7,283	13,674	6,422	15,563	4,793	9,075	10,655	20,490	7,129	17,477
R-squared	0.005	0.000	0.068	0.060	0.165	0.144	0.001	0.001	0.044	0.028	0.198	0.174

Standard errors in parentheses clustered by model number

*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions estimating the concurrent effect of the new standard (either 2004 or 2007) on the market average price of clothes washers. Columns (1), (3), (5), (7), (9) and (11) reproduce the results from the original regressions reported in Table 5. Columns (2), (4), (6), (8), (10) and (12) show the results of these regressions when non of the data omitted in the primary analysis is dropped. No fixed effects or controls are included.

Table 10: Within-Model Price Effect at New Standard Effective Dates with Omitted Data

	2004 Standard Change						2007 Standard Change					
	No Controls		Dryers as Controls		Room AC as Controls		No Controls		Dryers as Controls		Room AC as Controls	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dependent Var: Price	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data	Original	Including Dropped Data
Trend			-3.600***	-2.411***	-7.083***	-6.956***			-5.159***	-5.218***	-2.328***	-3.585***
			(0.548)	(0.538)	(0.905)	(0.733)			(0.648)	(0.486)	(0.795)	(0.515)
Standard			-1.683	-17.20***	36.10***	7.987			-2.954	-1.838	14.50*	7.675
			(4.290)	(5.001)	(7.230)	(5.841)			(4.202)	(3.837)	(7.629)	(5.116)
Trend * Standard			0.413	-2.384***	0.762	0.317			-2.438**	-4.408***	-0.744	0.586
			(0.974)	(0.855)	(1.171)	(0.933)			(0.984)	(0.833)	(1.306)	(0.851)
T * Trend	-4.342***	-4.181***	-0.743	-1.771*	2.741**	2.775**	-5.754***	-6.282***	-0.595	-1.063	-3.426***	-2.697***
	(0.815)	(0.924)	(0.976)	(1.059)	(1.220)	(1.175)	(0.835)	(0.759)	(1.056)	(0.900)	(1.158)	(0.920)
T * Standard	-36.58***	-23.75*	-34.90***	-6.548	-72.68***	-31.74**	-13.23**	-4.361	-10.28	-2.523	-27.73***	-12.04
	(11.16)	(12.77)	(11.87)	(13.56)	(13.34)	(13.97)	(6.383)	(7.042)	(7.639)	(8.007)	(9.981)	(8.736)
T * Trend * Standard	-3.054***	-3.235**	-3.468**	-0.851	-3.816**	-3.552**	-7.079***	-6.501***	-4.641***	-2.093	-6.335***	-7.088***
	(1.098)	(1.348)	(1.461)	(1.582)	(1.609)	(1.633)	(1.371)	(1.219)	(1.687)	(1.474)	(1.901)	(1.492)
Constant	739.1***	689.7***	634.3***	589.5***	603.6***	543.6***	799.2***	718.1***	714.6***	646.2***	663.0***	551.3***
	(11.36)	(11.39)	(5.985)	(5.744)	(6.907)	(5.511)	(9.330)	(7.732)	(5.389)	(4.187)	(6.549)	(4.386)
Model Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,637	6,562	7,283	13,674	6,422	15,563	4,793	9,075	10,655	20,490	7,129	17,477
R-squared	0.235	0.084	0.209	0.104	0.223	0.126	0.319	0.203	0.300	0.218	0.293	0.165
Number of Models	418	1,049	736	1,895	790	2,331	431	1,117	959	2,459	751	2,326

Standard errors in parentheses clustered by model number

*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions estimating the concurrent effect of the new standard (either 2004 or 2007) on the market average within-model price of clothes washers. Columns (1), (3), (5), (7), (9) and (11) reproduce the results from the original regressions reported in Table 6. Columns (2), (4), (6), (8), (10) and (12) show the results of these regressions when non of the data omitted in the primary analysis is dropped. Model specific fixed effects are included in all specifications. Regressions with fixed effects should be interpreted with caution, as some of the masked model numbers included here are aggregates of multiple models, and so fixed effects are not actually controling for all relevant time invariant characteristics in these regressions.