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Abstract

Minimum efficiency standards for products such as appliances are economically efficient when they correct a market failure. Negative ramifications of these standards, particularly for credit constrained or low-income consumers, such as increased prices or decreased choice, are contingent on the pricing behavior of suppliers. We use market point of sales data to estimate the change in price and efficiency of clothes washers following the change in United States minimum efficiency standards in 2004 and 2007, differentiated by market segment. With a relatively narrow confidence interval, the average price of the baseline market segment did not change significantly concurrent with either the 2004 or 2007 standard change, while efficiency of these products increased by 30%, resulting in significant financial savings for consumers of the least expensive baseline products. The highest efficiency products experienced a significant drop in price and increase in efficiency as well, particularly following the 2007 standard change. The results suggest that the effect of this increase in minimum efficiency standards for clothes washers was beneficial to all consumers, but particularly those with lower incomes or renters. Low-income consumers were not priced out of the market, but rather benefited particularly. We offer discussion of potential explanations of these findings.

1 Introduction

Minimum energy efficiency standards for energy consuming products, such as appliances and automobiles, are economically efficient when they correct a market failure (Houde and Spurlock, 2016). However, this type of regulation could cause manufacturers to drop the least expensive, least efficient products from the market, thereby increasing the price of products to those that can least afford it and reducing consumer choice (Gayer and Viscusi, 2013). This outcome may cause more consumers, particularly those with low incomes or who are credit constrained, to forego purchasing newer technologies, or possibly purchase from second-hand markets, which means they would be increasingly relying on less efficient, less reliable options. This could detrimentally impact their wellbeing, limit their ability to benefit from improvements in efficiency available in the new product market, and dampen the resultant energy efficiency improvement benefits from the regulation overall.

Any potential negative ramifications of minimum efficiency standards for credit constrained or low-income consumers are contingent on the pricing behavior of suppliers in the regulated market. If the markets are perfectly competitive with full pass-through of manufacturing cost variation to retail prices, then indeed one would expect suppliers to respond to the standard by eliminating products that become non-compliant, and to retain the prices of any products above the new standard. This would result in significant increases in overall market average prices, an increase that would be driven by inexpensive products being eliminated, which would disproportionally impact low-income or credit constrained individuals relying on these inexpensive products. However, if suppliers engage in strategic pricing, price discrimination behavior, or otherwise minimally pass through cost increases related to increasing product efficiency, the effect of an increasingly stringent regulation would not be so simple.

Indeed, several papers have been able to demonstrate that United States (U.S.) appliance minimum efficiency standards, particularly for clothes washers during the standard change analyzed in this paper, appear to be associated with declining or constant market average prices and increased product quality (Brucal and Roberts, 2019; Houde and Spurlock, 2015; Spurlock, 2013). These papers have pointed to several potential explanations for this effect, including market power and positive innovation externalities in the manufacturer market. In addition, product prices have tended to be lower than projected by the minimum standard rulemaking analyses for five different appliance types, and quality (as assessed by product ratings from Consumer Reports) has not been negatively impacted (Taylor et al., 2015). These findings indicate that something more is at play than simply the elimination of inexpensive products, reduction in consumer choice, and increase in average product prices. The natural follow-up question is, which types of consumers are being impacted by this regulation and how? Are some consumer segments facing a price increase while others are facing a price decrease? Is everyone benefiting equally? What are the implications for the most vulnerable consumers? Evidence regarding the equity and distributional impacts of many policies is needed. President Biden's administration is placing significant emphasis on energy and environmental justice, exemplified by Section 223 of the January 2021 Executive Order 14008 on "Tackling the Climate Crisis at Home and Abroad," which articulates the goal that 40 percent of the overall benefits from key investments should go to disadvantaged communities. These investments include energy efficiency. This goal is referred to as the

Justice40 Initiative (Biden, 2021a). Even more applicable to the context of the policies analyzed here is the Presidential Memorandum on Modernizing Regulatory Review issued by Biden-Harris administration on January 20th, 2021, which directs the U.S. Office of Management and Budget to “propose procedures that take into account the distributional consequences of regulations, including as part of any quantitative or qualitative analysis of the costs and benefits of regulations, to ensure that regulatory initiatives appropriately benefit and do not inappropriately burden disadvantaged, vulnerable, or marginalized communities” (Biden, 2021b).

There is a growing literature debating the equity and distributional implications of various energy policies, such as carbon taxes (Fischer and Pizer, 2019; Metcalf, 2019; Pizer and Sexton, 2019). Studies of the distributional implications of standards in an energy context have focused on Corporate Average Fuel Economy (CAFE) standards for automobiles. CAFE has been found to be regressive, particularly when impacts on used car markets are taken into account (Davis and Knittel, 2019; Jacobsen, 2013; Levinson, 2019; Metcalf, 2019). However, there are significant differences between the automobile setting and the appliance setting in general—and the clothes washer setting in particular—that are relevant to understanding regulatory impacts, particularly in a market with manufacturer market power. First, the correlation between vehicle price and fuel use or efficiency is not systematic; sports cars can be very fuel-intensive, but also expensive. In the case of clothes washers on the other hand, energy consumption and price are systematically negatively correlated; the least efficient products tend to be the cheapest.[1] Second, the correlation between income level and energy consumption of the vehicle purchased is also not systematic, low-income individuals purchase vehicles across the spectrum of energy intensity (Davis and Knittel, 2019). Again, in the case of clothes washers, low-income households are significantly less likely to have a low energy-intensity ENERGY STAR clothes washer compared to higher income households. Related to this is the prevalence of conditions that lend themselves to split-incentive or principal agent problems in the case of appliances like clothes washers, in large part due to the nature of the home rental market.[2] Because of these differences the distributional implications for clothes washer efficiency standards are likely to be very different from fuel efficiency standards for automobiles, which is indeed what we find.

In this paper we retrospectively assess the change in efficiency and market price that occurred concurrent with a change to the minimum efficiency standard using actual market data. However, unlike previous studies taking this approach (Brucal and Roberts, 2019; Houde and Spurlock, 2015; Spurlock,

[1] We note here that this is not true for all types of appliances. For example, the relationship between price and energy use for refrigerators is the opposite from that of clothes washers (likely because premium refrigerator models tend to be larger, and therefore consume more energy). See Appendix A for more on the relationship between energy consumption and price for refrigerators and clothes washers as an illustrative example.

[2] See Section 3 for a more detailed discussion of the relationship between income and rental status and clothes washer efficiency, and research on the principal-agent problem.

2013), we differentiate the change in price and efficiency across market segments, with baseline products on the low-end of the market, and the highest efficiency ENERGY STAR products on the high end. If the market were efficient, without any structural or behavioral market failures, we would expect to see an increase in the average price of baseline (i.e., low-end or mass-market) products accompanying the standard-driven increase in efficiency, and the question would then be how to weigh the tradeoff in improved efficiency and resulting reduced operating costs with the observed increase in upfront cost to assess the extent to which consumers of this market segment of products were negatively or positively impacted by the regulation. However, at the risk of foreshadowing the results, we show this is not the pertinent question to ask, at least not in this case. We find that low-income consumers were not in fact priced out of the market, but rather benefited particularly. We discuss potential implications of this for the distributional impact of this type of regulation and specifically how it affects the lowest income and most vulnerable consumers. We provide a discussion of potential explanations for our observations and invite researchers to dig more deeply into the empirical outcomes of this type of policy to confirm, refute, or better explain these observations.

The remainder of the paper progresses as follows. Section 2 provides background on U.S. energy efficiency regulation; Section 3 discusses the market structure of the U.S. clothes washer market, and summarizes the literature on the relationship between market structure and minimum quality standards regulation; Section 4 provides a discussion of distributional differences in efficiency adoption and access, and market failures contributing to these patterns, relevant to the clothes washer market; Section 5 describes the data used for this analysis; Section 6 describes our estimation methodology; Section 7 presents our results; and Section 8 concludes.

2 Background

There are three contextual factors that are relevant for understanding the motivation for, and implications of, the results presented here. First is the U.S. energy efficiency regulatory context and history, which is presented in subsection 2.1. Second, in subsection 2.2 we provide relevant background and context on the structure of the U.S. clothes washer market, and the implications of market structure and concentration for the regulatory policy being studied. Finally, in subsection 2.3 we provide detailed background on the consumer side of the clothes washer market, which is relevant for understanding the impact of market structure and the regulatory policy being analyzed on the equity implications of our findings.

2.1 Background on Energy Efficiency Regulation in the U.S.

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

2.1.1 U.S. Federal Clothes Washer Policies over Time

Clothes washers were among the initial set of products for which NAECA established minimum efficiency standards. In 1987 Congress adopted the first federal standard for clothes washers, with compliance required in 1988. DOE adopted the second federal clothes washer standard in 1991, with compliance required in 1994. This analysis focuses on the third federal clothes washer standard, adopted by DOE in 2001, which included a two-tier compliance schedule. The first phase required compliance on January 1st, 2004, and the second phase on January 1st, 2007.

Clothes washers are also covered by the ENERGY STAR labeling program. This is not a restrictive standard, but rather establishes a benchmark of efficiency, above which products qualify for the voluntary ENERGY STAR label, signaling a model's high efficiency to potential customers. ENERGY STAR labeling criteria are often tied to the level of the minimum efficiency standard (e.g., 10 percent less energy consumed than the standard level), however they can also change independently from minimum standards. Table 1 provides a breakdown of the federal minimum efficiency and ENERGY STAR standards for clothes washers enacted between 1991 and 2011.

Table 1 U.S. Federal Clothes Washer Minimum Efficiency and ENERGY STAR Standards between 1991 and 2011

Year	Compact	Standard	ENERGY STAR
1994	EF ≥ 0.9	EF ≥ 1.18 (TL only)	-
2001	-	-	MEF ≥ 1.26
2004	MEF ≥ 0.65	MEF ≥ 1.04	MEF ≥ 1.42
2007	-	MEF ≥ 1.26	MEF ≥ 1.72; WF ≤ 8.0
2009	-	-	MEF ≥ 1.80; WF ≤ 7.5
2011	-	MEF ≥ 1.26; WF ≤ 9.5	MEF ≥ 2.00; WF ≤ 6.0

Notes: Before 2004, the minimum efficiency standard was based on the Energy Factor (EF), which measures efficiency in terms of cubic feet per kilowatt-hour (kWh) per cycle. In 2004 the minimum efficiency standard became based on the Modified Energy Factor (MEF). The MEF, also measured in cubic feet per kWh per cycle, expanded upon the EF by incorporating the energy required to dry moisture remaining in the clothing following the final spin cycle. Similarly, starting in 2001 the ENERGY STAR benchmark (only established for standard-size models) was based off of the MEF. Beginning in 2007, the ENERGY STAR benchmark also became contingent on the Water Factor (WF), which is the number of gallons per cycle per cubic foot used by the washer. While the standards for clothes washers differ between compact and standard-size models, the majority (approximately 99 percent) of observations in our data are standard-class (defined as washers with capacity greater than 1.6 cubic feet).

2.2 Clothes Washer Market Structure and Context

In this subsection we provide some relevant context on the degree of concentration in the U.S. clothes washer market with respect to clothes washer manufacturers. In addition, we outline the theoretical prediction pertaining to how this type of oligopolistic market structure, in which firms would be able to engage in second-degree price discrimination, would be expected to interact with minimum efficiency standard policy.

2.2.1 Market Concentration among Manufacturers in the U.S. Clothes Washer Market

The U.S. clothes washer market is highly concentrated at the level of clothes washer manufacturers, meaning that manufacturers are not price-takers and are able to exert power in this market. The Herfindahl-Hirschman Index (HHI) calculated annually using our data ranges between 0.26 and 0.40 over this time period (2002 - 2008), with an average of 0.33 across all years. An HHI greater than 0.25 is a common criterion used to define a highly concentrated market. These values are in line with calculated by Fischer (Fischer, 2005), who found HHI values of between 0.29 and 0.36 for laundry products and clothes washers, respectively.

To further elucidate this point, Fig. 1 shows the market share by manufacturer for each year between 2002 and 2009 based on our data; the top six manufacturers and their brand subsidiaries held over 90 percent of the market share throughout this period, with earlier years exhibiting even higher levels of concentration.

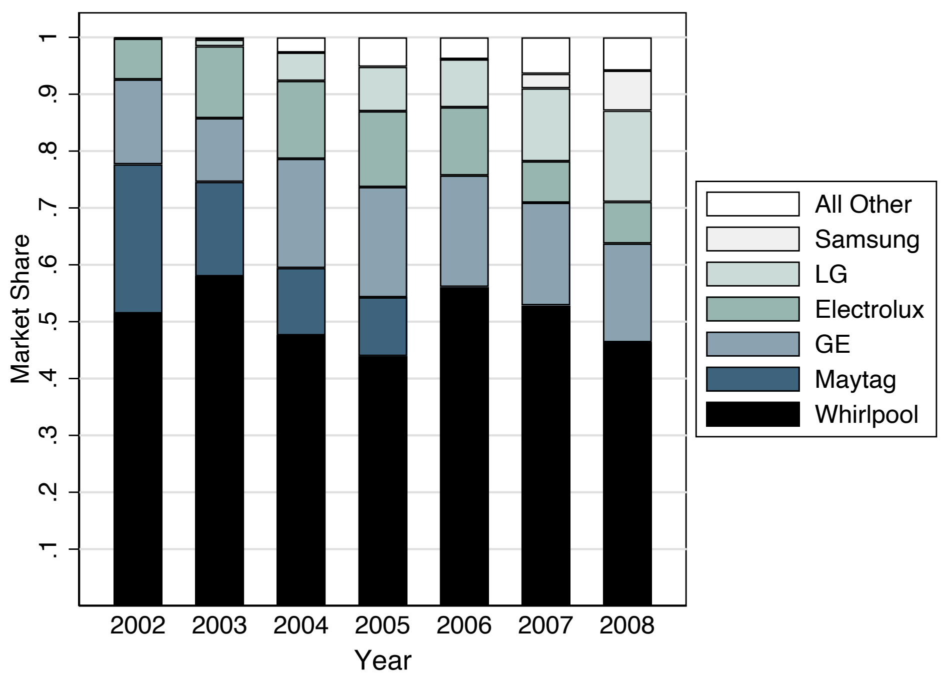

Figure 1. Market Shares of Manufacturers by Year: this figure shows the market share of the largest manufacturers and their brand subsidiaries by year for models with brand provided (models with masked model number, described in Section 5, also had masked brand). Note that Whirlpool acquired Maytag in early 2006. See Appendix B for detail

on the categorization of brands and their subsidiaries as well as the list of brands in the "All Other" category.

Empirical work has demonstrated that this level of concentration for appliance markets has had measurable impacts on prices and product menus. For example, the 2006 merger of Maytag and Whirlpool resulted in an increase in price and decrease in product variety for some appliances, an outcome consistent with consolidating market power (Ashenfelter et al., 2013). Additionally, the market response to the 2008 change to the ENERGY STAR criteria for refrigerators was shown to be consistent with the classic Mussa and Rosen (Mussa and Rosen, 1978) second-degree price discrimination model, indicating that suppliers are able to strategically segment the market and price products in such a way that allows them to extract more consumer surplus (Houde, 2022). More recently, evidence was found that an observed decline in a quality-adjusted price index concurrent with more stringent standards resulted primarily from increased entry and exit of models within the same manufacturer, indicating that the mechanism for this index decline might more likely be positive externalities associated with product innovation, rather than market power (Brucal and Roberts, 2019), though we would note that these two mechanisms may be related.

2.2.2 Market concentration, second-degree price discrimination, and minimum quality standards

Residential clothes washers are one of many residential energy consuming durable goods covered by the U.S. federal Appliance and Equipment Standards Program, and there are reasons to believe that market structure is likely to be an important factor in the price and product menu impacts of energy efficiency standards in a variety of the markets covered by this program. For example, the following is a synopsis from interviews conducted with residential furnace manufacturers in support of DOE analyses:

> During interviews, all manufacturers agreed that if DOE set amended energy conservation standards too high, increased standards could limit their ability to differentiate residential furnace products based on efficiency. As the standard approaches max tech,[3] manufacturers stated that there would be fewer performance differences and operating cost savings between baseline and premium products. They were concerned the drop in differentiation would lead to an erosion of markups for top efficiency products. Thus, the manufacturers' profitability would decrease with compressed product offerings and markups. (U.S. Federal Register, 2015)

This quote underlines the fact that furnace manufacturers are likely to respond to a new minimum efficiency standard in more nuanced ways than by simply eliminating non-compliant models. In this case manufacturers indicate that decreased product differentiation resulting from the standard would be likely to result in erosion of markups on high efficiency products. As discussed in more detail below, this

[3] The term "max tech" is used in the Technical Support Documents published by DOE in support of the appliance standards program, and refers to a theoretical maximum that could be achieved by combining all available efficiency-improving measures. It is possible that manufacturers would interpret “max tech” to be the highest efficiency models currently on the market.

pattern is consistent with the behavior of firms engaging in second-degree price discrimination. These types of dynamics can have significant implications for the overall welfare impacts of the regulation, but also for the distributional impacts across consumers. While clothes washers and residential furnaces are different products, due to the level of concentration in the clothes washer market discussed above, we expect that clothes washer manufacturers are able to exert some power in the market. The strategy of second-degree price discrimination is precisely suited to a setting with heterogeneity in preferences for efficiency across consumers coupled with quality-differentiated products, as is the case in the clothes washer market.

Here we discuss the intuition behind second-degree price discrimination and how a market where this pricing strategy is present is predicted to respond to a minimum quality standard.[4] In particular we highlight how these standards are likely to differentially impact customer segments. In the classic model of a monopolist engaging in second-degree price discrimination in a quality-differentiated goods setting, the firm under-provides quality to the low-end, or "baseline," market segment relative to the socially optimal quality level that would be supplied to these customers by a perfectly competitive market (Mussa and Rosen, 1978). [5] They do this in order to charge a higher premium and extract additional profits on products targeted to "high-type" customers, or customers with a high willingness to pay for quality. The suppression of quality on the low-end ensures that high-type customers are not willing to switch down and buy the low-type products. In essence, the unregulated monopolist provides an economically inefficient range of quality relative to the welfare-maximizing case (i.e., quality supplied to the market segment with the lowest willingness to pay is too low), and because of this, prices charged to the highest type market segment are able to be raised above the welfare maximizing price for this category of products.

Given that the critical lever allowing the monopolist to charge elevated premiums on high quality products is the ability to suppress quality on the low-end, the key policy question then becomes, what results when a minimum quality standard is imposed? It has been shown that, just as the furnace manufacturers referenced in the quote above suggested, the increase in quality required by the standard on the low-end temporarily reduces the degree of quality differentiation in the market making it impossible to maintain the same price margins on higher quality products (Besanko et al., 1988, 1987; Fischer, 2005). The difference in quality between basic and premium products decreases, so high-type customers are now more likely to be willing to switch down to the lower quality product in order to avoid the high markups on the premium products. In order to avoid losing the profits from more profitable premium product sales to those high-type customers the monopolist then finds it preferable to reduce those markups. This means the prices of premium products fall when the new standard is

[4] More detail on this model in this context is provided in Appendix C.

[5] Other studies have also explored this practice in a monopoly setting (de Meza and Ungern-Sternberg, 1982; Donnenfeld and White, 1988).

imposed.

Even when relaxing the monopoly assumption in models similar to that discussed above to allow for duopoly, oligopoly, or monopolistic competition (i.e., markets with more than a single monopoly supplier, but still concentrated enough for suppliers to exert market power), the unregulated case results in a suppression of quality on the low-end below the socially optimal level, and high-end prices higher than socially optimal. In particular, in a case with multiple firms each selling a range of product quality, and with market power due to brand loyalty, there are higher margins on the high-end segments of the market, and more competition in the low-end of the market (Katz, 1984). This means sales of high-end products are more profitable, and it is therefore more important to capture and maintain the loyalty of consumers on the high-end relative to the low-end. For this reason, quality on the low-end is pushed downwards to prevent high-type customers (who are charged higher markups) from switching down. A key assumption in this case is that consumers who are more quality-conscious are also more brand-conscious. Others have demonstrated that a monopolistically competitive market can result in an even wider range of quality and even higher prices than in the monopoly case (de Meza and Ungern-Sternberg, 1982).[6]

The theoretical impacts of minimum quality standards on quality-differentiated markets that are oligopolistic or monopolistically competitive have also been explored. Following a new minimum quality standard, producers that have market power have an incentive to expand quality upwards to increase the spread of quality in the market again following the new standard (Crampes and Hollander, 1995; Ronnen, 1991). They do this to alleviate the increased price competition between products imposed by the quality distribution collapse following the new standard. However, because of increasing marginal costs, high quality producers raise quality less than the increase in quality on the low end induced by the minimum quality standard. Therefore, price competition still intensifies, causing prices (controlling for quality level) to drop.[7]

In the context of this paper, the relevant “quality” attribute over which firms may segment the market is energy efficiency. Most literature to-date addressing price discrimination in the context of energy

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[6] More recent theoretical literature has returned to the price discrimination model and found some more ambiguous results when the market is oligopolistic (Armstrong and Vickers, 2001; Fischer, 2012; Rochet and Stole, 2002). However, the equilibria in these models are not always unique (Armstrong and Vickers, 2001), and are highly sensitive to the necessary assumption that brand and quality preferences are uncorrelated (Armstrong and Vickers, 2001; Rochet and Stole, 2002). This remains an empirical question, but there is substantial evidence that brand loyalty and perceived quality are positively correlated (Chaudhuri and Holbrook, 2001).

[7] In the extension of the model allowing the quality costs to be variable (Crampes and Hollander, 1995) instead of fixed (Ronnen, 1991) finds the same qualitative results. However, while the fixed costs case showed that consumers necessarily gain from a minimum quality standard, the variable costs case shows that consumer welfare increases only if the high-quality firm does not respond by raising quality too drastically.

efficiency standards regulation has focused on the automobile market and implications of CAFE standards, or are primarily theoretical (Fischer, 2012, 2005). The somewhat limited empirical work touching on this in the case of appliances provide some evidence of patterns consistent with price discrimination (Brucal and Roberts, 2019; Houde, 2022; Spurlock, 2013). An in-depth review of the economic rationale and implications of minimum efficiency standards for appliances also includes a discussion of market power (Houde and Spurlock, 2016).

2.3 U.S. Consumers of Clothes Washers

In this subsection we discuss the degree of heterogeneity present in preferences and willingness to pay for efficiency among U.S. consumers of clothes washers. Of particular relevance for interpretation of the results of this study are the sources of this heterogeneity, and the correlation with household income. Evidence pertaining to both of these factors from data and related literature are presented here.

2.3.1 Heterogeneity in Preference among U.S. Consumers of Clothes Washers

For firms to engage in strategic price discrimination, it must be the case that consumers exhibit significant heterogeneity in preferences for product features. Of particular relevance for this paper is the degree of heterogeneity in preferences for energy efficiency.

There are many reasons why preferences for efficiency vary across consumers. First, some consumers might have very high willingness to pay for efficiency because they are environmentally conscious and have preferences for “green” products, while others do not (Ward et al., 2011). Second, discount rates vary across consumers leading to variation in consumers’ weighting of future energy-cost savings (Newell and Siikamäki, 2014). Third, some consumers that purchase appliances may not actually pay for the operating costs of their choice. This happens when a landlord purchases an appliance but their tenant is the one paying for the energy it consumes. This creates a classic principal-agent problem, or split-incentive market failure (Laffont and Martimort, 2009). We discuss evidence of the principal agent problem in this context in more detail below. Fourth, the degree to which consumers are subject to imperfect information regarding the efficiency of the products they purchase may vary. It has been shown that, because of the coarseness of the information provided on the U.S. EnergyGuide label, consumers are likely to be systematically misinformed about the operating cost savings resulting from more efficient products (Davis and Metcalf, 2016). Finally, low-income consumers may have a preference for energy efficiency, but may be credit constrained and therefore unable to pay the high premiums for more efficient products.

Of particular relevance to this paper are those sources of heterogeneity in willingness-to-pay for efficiency that incentivizes suppliers with market power to engage in profit-maximizing market segmentation behavior, which can limit access to efficiency for low-income or otherwise disenfranchised users of the product. This disenfranchised population is likely sizable. Between 33 and 65 percent of consumers appear to not take efficiency into account at all in their refrigerator purchase decision (Houde, 2018). This degree of heterogeneity in the preferences and decision processes of consumers is significant, and something that strategic firms with market power are not likely to ignore in their product design and pricing decisions. The fact that one to two thirds of the population appeared to not take efficiency into account at all is notable, and is likely to include customers with no choice but to purchase based off of first-price alone (i.e., those who are highly credit constrained) or those that will not be internalizing the operating cost implications of their choice (i.e., landlords purchasing appliances for use by tenants who will be paying the energy bill, often referred to as the "landlord-tenant problem").

2.3.2 Household Income and Willingness-to Pay-for Efficiency: credit constraints and the landlord-tenant problem

Supporting the interpretation of this heterogeneity in preferences for clothes washer efficiency stemming at least in part from either credit constraints or the landlord-tenant problem, we see that income does correlate significantly with energy efficient product ownership and the probability of being a tenant as opposed to a homeowner. For example, according to the 2009 Residential Energy Consumption Survey (RECS), consumers with incomes at or below the poverty level were half as likely to own an ENERGY STAR clothes washer as compared to consumers with incomes above the poverty level. Additionally, consumers at or below this same income threshold were over twice as likely to rent their homes (i.e., 60 percent as compared to 27 percent for higher income individuals). While those above the poverty level were more likely to have a clothes washer in their home, still the majority (64 percent) of those at or below this income threshold had a clothes washer in their home. Of those low-income individuals that both had a clothes washer in their home and rented, 87 percent paid the electricity associated with operating these appliances. This means they were likely subject to a scenario in which their landlord purchased the appliance, but they paid the operating costs.

A comprehensive analysis to determine if indeed renters were less likely to have energy efficient appliances compared to home owners using data from the 2005 RECS survey showed a consistent set of patterns: renters had annual household incomes of around $34 thousand on average as compared to about $56 thousand for homeowners, and it was found that renters were significantly less likely to own ENERGY STAR clothes washers, refrigerators or dishwashers (Davis, 2012). This effect was robust to inclusion of a variety of control variables.

While they did not focus on clothes washers specifically, another analysis of 2005 RECS data found that conditions leading to split incentives between renters and owners or buyers and sellers exist in 25 percent of refrigerator energy use, 66 percent of water heating energy use, and 48 percent of space-heating energy use in U.S. residences (Murtishaw and Sathaye, 2006). The landlord-tenant problem, a specific case of the principal-agent problem, has been confirmed in the case of residential energy consumption repeatedly in more recent studies. The principal-agent split incentive problem was prominent in the case of both heating and cooling behavior and the presence of insulation (Gillingham et al., 2012). More recently it was found that tenants are relatively uninformed about the energy costs associated with rental properties (Myers, 2020). The implication of this type of asymmetric information is that landlords truly have no incentive to invest in the energy efficiency of their rental units because there is no credible mechanism for them to capitalize the value of that investment into rental prices.

In essence, because of the negative correlation between price and energy consumption for clothes washers, the presence of the principal-agent problem, and the share of consumers that appear to make their appliance purchase decisions without taking efficiency into account at all (in part because of the split-incentive issue present in this market), firms with market power are likely to use energy efficiency as a feature over which to segment the market for clothes washers. This means that firms have an incentive to underprovide efficiency for the baseline low-end products, and charge high premiums for more efficient high-end products. A minimum efficiency standard in this setting would force firms to increase the efficiency of the low-end products. This is likely to benefit low-income consumers by increasing the efficiency of products being targeted to their market segment and by increasing the efficiency of products available for landlords to purchase for use by tenants. However, the benefit of increased efficiency to low-end consumers may be counteracted if manufacturers increase prices of baseline low-end products. In the remainder of the paper, we undertake an analysis of the effect of increasingly stringent standards effective in 2004 and 2007 on clothes washer prices to determine how this trade-off between benefits and costs for low-income consumers and tenants played out in the case of these clothes washer minimum efficiency standards.

3 Data

We use nationally representative point-of-sale data from NPD Group, consisting of nationally aggregated monthly total revenue and total quantity sold by individual model number.[8] These data are acquired from an extensive set of U.S. retailers.[9]

Because the NPD data do not include energy usage, we match them by model number and year to three additional data sources: (1) the Federal Trade Commission (FTC) appliance energy database, (2) the ENERGY STAR database, and (3) the California Energy Commission (CEC) appliance energy database. The FTC data provide a measure of kilowatt hours (kWh) per year energy usage by year and appliance model number, which corresponds to the EnergyGuide label posted on products at the point of sale. Some observations in the NPD data include model numbers that are masked to maintain the anonymity of participating retailers. These include products with retail brands, like Kenmore for example, which are only sold by Sears. Unfortunately, because the model numbers are masked, these observations cannot be matched to the energy usage data sources. In addition, there are some model numbers that are not masked, but otherwise do not match model numbers in any of the energy use databases. Where possible these observations are maintained in the data.

The metrics used to determine the compliance of washer models with minimum efficiency standards and ENERGY STAR criteria in 2004 and 2007 are the Modified Energy Factor (MEF) and Water Factor (WF). The MEF includes the cubic feet per kWh per cycle used by the washer unit, and also accounts for the energy required to dry moisture remaining in the clothing following the final spin cycle. The WF

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

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

accounts for the number of gallons per cycle per cubic foot used by the washer. The ENERGY STAR and CEC data provide these measures for over half the models used in our primary analysis. For the rest, we estimate a proxy MEF.[10]

3.1 Data Preparation and Cleaning

We conducted the following initial data preparation and cleaning steps. First, we defined our study period, which included January 2002 through November 2008 (December 2008 is missing from the data from NPD Group). We chose to focus our analysis on this period to avoid possible conflating of the impact of changes to the minimum efficiency standards of interest with changes to the ENERGY STAR criteria alone that came into effect in 2009 (see Table 1). Within that study period we cleaned the data in the following ways. First, we dropped models for which all observed nominal prices for that model were either more than $4000 or less than $40. This dropped 3 models (a total of 4 observations). Next, we replaced any remaining price observations of more than $4000 or less than $40 with the average price for that model absent those observations. This affected 78 observations (less than 0.30% of the data). Finally, we dropped all observations with quantity sold less than the tenth percentile for that month, thereby focusing the analysis on the highest 90th percentile of products in terms of sales each month. This step retains 90% of the observations, and retains 99.03% of the data in terms of quantity sold in the market. We did this to align with data cleaning steps used by other analyses of similar data (Ashenfelter et al., 2013). The rationale is to focus the analysis on the models making up the vast majority of sales in the market, and eliminate a small amount of outlier observations that could be present due to coding error, or are more likely to be outliers in terms of their price or quantity sold in the market. The objective is to understand the distributional impact of standards on the prices of different product types on average while avoiding bias from unnecessary measurement error or significant outliers to the extent possible.

3.2 Defining Market Segments by Efficiency Level

Our analysis presents the change in efficiency and price concurrent with the energy efficiency policy change broken out by market segments defined in terms of clothes washer energy efficiency levels. Fig. 2 presents a visual explanation of our approach to distinguish market segments. There are conceptually five strata of efficiency that can fully describe the potential product space during the study time period: (1) MEF<1.04 eliminated by the minimum standard in 2004; (2) 1.04≤MEF<1.26 compliant after 2004 but eliminated by the 2007 standard; (3) 1.26≤MEF<1.42 ENERGY STAR-qualified prior to 2004 but disqualified in 2004; (4) 1.42≤MEF<1.72 ENERGY STAR-qualified before and beyond 2004 but disqualified in 2007; and (5) 1.72≤MEF ENERGY STAR-qualified all the way through the study period.

[10] See Appendix E for more details on estimating the Proxy MEF.

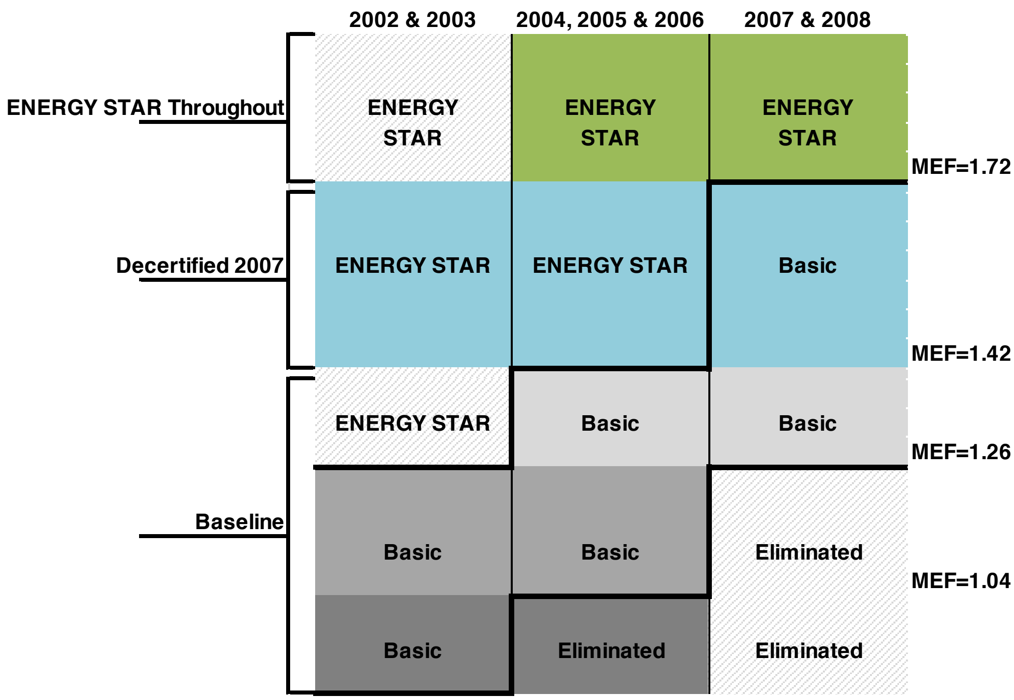

Figure 2. Definitions of Clothes Washer Market Segments: This figure shows the definitions of energy consumption defined strata in the clothes washer market. "Eliminated" indicates products with modified energy factor (MEF) levels below the standard at that time, "Basic" indicates products that meet the minimum standard but do not meet the ENERGY STAR criteria, and "ENERGY STAR" indicates models that meet the criteria for the ENERGY STAR label at that time. Boxes with lined backgrounds (MEF<1.26 in 2007 and 2008; 1.26≤MEF<1.42 in 2002 and 2003; 1.72≤MEF in 2002 and 2003) indicate strata with minimal observations in the data during those time periods. The bottom three strata, shown in gray, are combined to define the Baseline market segment for purposes of the analysis while the top two are maintained separately as the Decertified 2007 segment and the ENERGY STAR Throughout segment.

Many of these five strata had only a small residual of models being sold just before or just after a given standard change (Fig. 3). For example, there were only a residual few products sold in the 1.26≤MEF<1.42 range prior to 2004, or in the 1.04>MEF range after 2004 and the 1.26≤MEF<1.42 range after 2007. We therefore combine the three lowest strata of efficiency in our analysis to estimate an average change in baseline/low-end segment price and efficiency. This results in three market segments used in the analysis: (1) *Baseline* (MEF<1.42), which, based on our data, captures the low-end, non-ENERGY STAR qualifying, market for clothes washers through the study period; (2) *Decertified 2007* (1.42≤MEF<1.72); and (3) *ENERGY STAR Throughout* (1.72≤MEF).

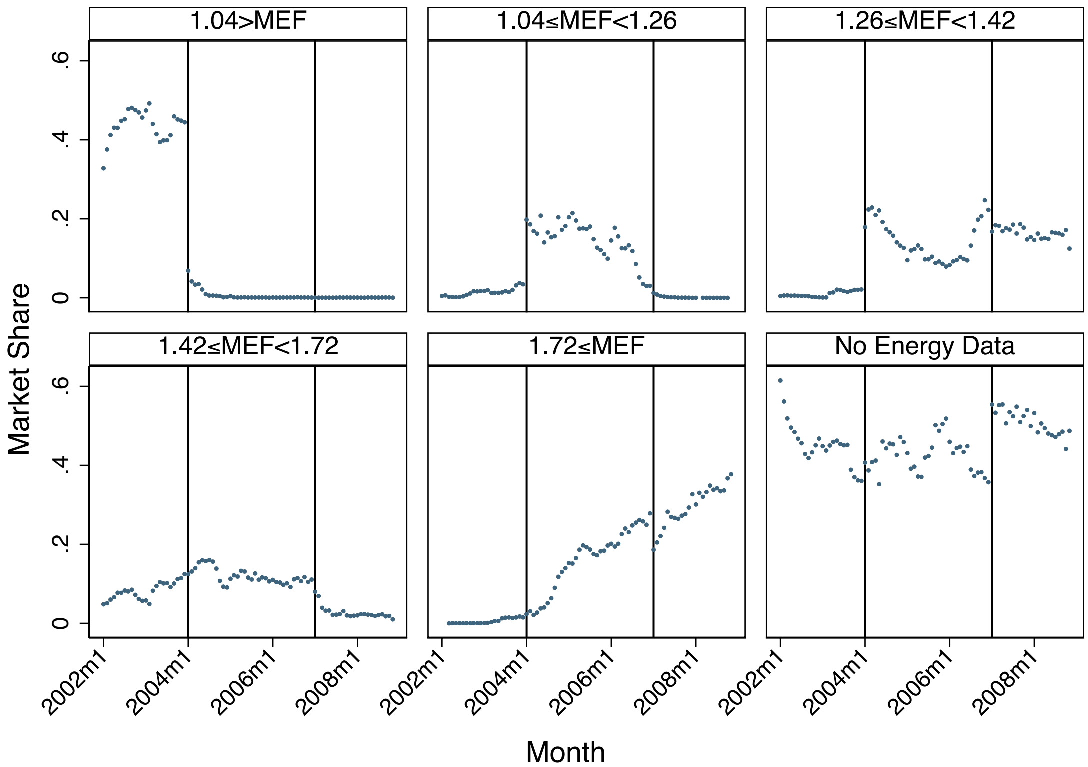

Figure 3. Market share over time of five strata of efficiency & those with no energy data: This figure shows the market share of the five strata of efficiency defined by dividing the market by modified energy factor (MEF), plus the market share of those products that cannot be matched to energy data and so cannot be categorized into these strata. Compliance dates of the standard changes (January 2004 and January 2007) are shown with vertical lines.

3.3 Summary Statistics

Table 2 reports summary statistics for the full cleaned dataset, including both models with energy data, and for those without energy data (that therefore cannot be categorized into one of the three market segments).[11] Table 3 reports summary statistics for the three primary market segments used in the analysis (representing only models with energy data). These statistics demonstrate how the price for the full market changes by very little, both in terms of the mean and in terms of the spread of prices, summarized by the standard deviation. Models with no energy data are not notably different in this regard. The baseline market segment prices decrease on average by 10%; for the Decertified in 2007 market segment prices decrease by 53%; and for the ENERGY STAR Throughout market segment prices decrease by 32%. Average energy efficiency for those models in the full market for which we can

[11] The summary statistics reported here are not quantity weighted. Tables with quantity weighted summary statistics can be found in Appendix F.

observe this value increases over 60% from prior to the 2004 standard to after the 2007 standard. This increase is driven largely by the Baseline models, which increase in efficiency on average by 30%, and also by the highest efficiency ENERGY STAR Throughout models, which increase in efficiency by 10%. In 2002 and 2003 the market is made up of only 15% front loader washers, whereas this increases to 43% following the 2007 standard. Front loader washers are concentrated largely in the highest efficiency market segments. In addition, high efficiency top loading washers surge in the highest efficiency market segment during this time period, moving from 0% prior to 2004 to up to 17% of the ENERGY STAR Throughout market segment after 2007. The Baseline market segment is dominated by historically U.S.-based manufacturers (GE, Maytag, and Whirlpool) as well as Electrolux, which is Swedish-based. On the other hand, the highest efficiency market segment is made up of primarily European (Bosch) and Korean (LG) manufacturers prior to 2004, but by 2007 and 2008 GE, Electrolux and, in particular, Whirlpool have started offering significant numbers of models of that efficiency level.

Table 2 Summary statistics for all models and for those with no energy data separated out

	All models			**Models with No Energy Data**		
	2002-2003	2004-2006	2007-2008	2002-2003	2004-2006	2007-2008
	Count			Count		
Models	664	922	937	470	555	477
Observations	5,485	10,923	10,429	3,109	5,203	5,065
Quantity Sold (Thousands)	4,107	7,534	10,039	1,855	3,210	5,130
	Mean (Std. Dev.)			Mean (Std. Dev.)		
MEF	1.12	1.51	1.84			
	(0.30)	(0.38)	(0.47)			
Price (2011 Dollars)	628	664	646	592	584	560
	(378)	(400)	(339)	(352)	(367)	(309)
Front Loader (%)	15	28	43	15	26	36
	Percent of Models in Market			Percent of Models in Market		
Bosch (%)	1	2	3	1	1	1
Electrolux (%)	16	14	13	16	16	12
GE (%)	19	17	14	19	15	8
LG (%)	1	5	6	1	3	1

Maytag (%)	24	14	0	25	13	0
Other (%)	9	10	25	13	16	45
Samsung (%)	0	1	4	0	1	4
Whirlpool (%)	30	38	36	25	36	29

Notes: The MEF statistics in the "All models" column reflect only those models for which we observe energy data. These include, in 2002-2003: 194 models, 2,376 observations, 2,252 thousand units sold; in 2004-2006: 367 models, 5,720 observations; 4,324 thousand units sold; and in 2007-2008: 460 models, 5,364 observations, 4,909 thousand units sold. All other statistics in those columns are derived from the full number of models and observations listed in the table. Standard deviations are reported in parentheses. † Price reported in December 2011 Dollars.

Table 3 Summary statistics for each of the three analysis market segments

	Baseline (MEF<=1.42)			**Decertified 2007 (1.42<MEF<=1.72)**			**ENERGY STAR Throughout (1.72<MEF)**		
	2002-2003	2004-2006	2007-2008	2002-2003	2004-2006	2007-2008	2002-2003	2004-2006	2007-2008
	Count			Count			Count		
Models	158	206	164	23	71	44	23	105	253
Observations	1914	2982	1788	357	1228	455	104	1510	3121
Quantity Sold (Thousands)	1892	2185	1683	338	891	282	22	1214	2944
	Mean (Std. Dev.)			Mean (Std. Dev.)			Mean (Std. Dev.)		
MEF	0.99	1.22	1.29	1.58	1.56	1.57	2.00	2.04	2.19
	(0.10)	(0.13)	(0.10)	(0.09)	(0.10)	(0.09)	(0.13)	(0.23)	(0.25)
Price†	542	509	490	1202	814	564	1304	1125	889
	(254)	(254)	(237)	(482)	(418)	(290)	(303)	(351)	(314)
Front Loader (%)	2	1	0	65	28	13	100	86	83
	Percent of Models in Market			Percent of Models in Market			Percent of Models in Market		
Bosch (%)	0	0	0	0	0	0	39	11	10
Electrolux (%)	16	10	13	20	18	13	0	12	14
GE (%)	22	21	26	12	26	28	0	5	14

LG (%)	0	0	0	0	0	0	30	29	17
Maytag (%)	21	16	0	37	20	0	0	7	0
Other (%)	0	3	1	10	5	9	31	12	8
Samsung (%)	0	0	0	0	0	0	0	0	5
Whirlpool (%)	41	51	60	22	31	51	0	24	32

† Price reported in December 2011 Dollars.

Note: Standard deviations reported in parentheses.

4 Analysis Method

In this section we outline the approach we use to analyze the change in market outcomes differentiated by market segment that occurred concurrent with the changes in standard. To do this we use a regression method, chosen in order to statistically estimate the changes in price and efficiency for Baseline, Decertified 2007, and ENERGY STAR Throughout market segments. A regression method is selected due to the ease with which results can be interpreted, and the way in which the degree of statistical significance of the results can be identified after appropriately accounting for potential serial correlation in the data, as the data consist of a panel of observations of individual clothes washer models over time. In order to account for potential correlation over time of observations for a given clothes washer model, the standard errors are clustered at the individual model number level.

The primary estimating equation is presented in Equation (1). We correlate changes in the standard with two different outcome variables (y_{itj}): price (in December 2011 dollars) and MEF. Each of the outcome variables is observed for each time t for each model i in market segment j. The term $Standard04_t$ is a dummy variable that changes from zero to one in January 2004 (when compliance was required for the first-tier clothes washer standard) and remains equal to one thereafter. The term $Standard07_t$ is similarly defined, equaling zero up until January 2007 at which point it is equal to one for each time period thereafter. The j subscript is an indicator for each of the elements in the set of three efficiency-based market segments defined in Fig. 2 as well as the models with no energy data that cannot be categorized into one of these market segments, $j \in$ {Baseline; Decertified 2007; ENERGY STAR Throughout; No Energy Data}. We run separate regressions for each of these four categories. We run the regressions with and without weighting by model market share. The parameters of interest are $\beta_{04,j}$ and $\beta_{07,j}$.

$$y_{itj} = \alpha_j + \beta_{04,j} Standard04_t + \beta_{07,j} Standard07_t + \varepsilon_{itj} \qquad \text{(Eq.1)}$$

The objective is to estimate the average change in price and efficiency of products available after compliance with each of the new standards is required relative to before. The questions we seek to answer are: (1) for an average consumer walking into an appliance store after the standard, would the product selection available to them look different than if they walked in a year prior (answered with the unweighted regression), and (2) would the average purchase made have been different had they walked in a year prior (answered with the quantity-weighted regression). These changes, if present, could be due to a number of factors including macroeconomic changes. However, because the mechanism of a change in MEF related to the standard changes is clear, the implication is that much of the result is driven by the policy itself.

5 Results

Fig. 4 graphically presents the temporal patterns in price and efficiency across market segments. The lower panel of Fig. 4 shows that the average efficiency level of the low-end Baseline products increased to almost the level of the 2007 standard as compliance was required with the new standard in 2004, likely in anticipation of the future additional increase. There is also an increasing trend in the average efficiency of products in the ENERGY STAR Throughout market segment starting at the 2004 standard. The top panel of Fig. 4 shows the concurrent patterns in product prices; the Baseline market stays at a flat average price; products in the Decertified in 2007 segment start declining in price at 2004 and are sold at price levels consistent with Baseline products by the time they are decertified in 2007; and finally, the most efficient products became cheaper and cheaper even as the level of efficiency of those products ratcheted up further and further.

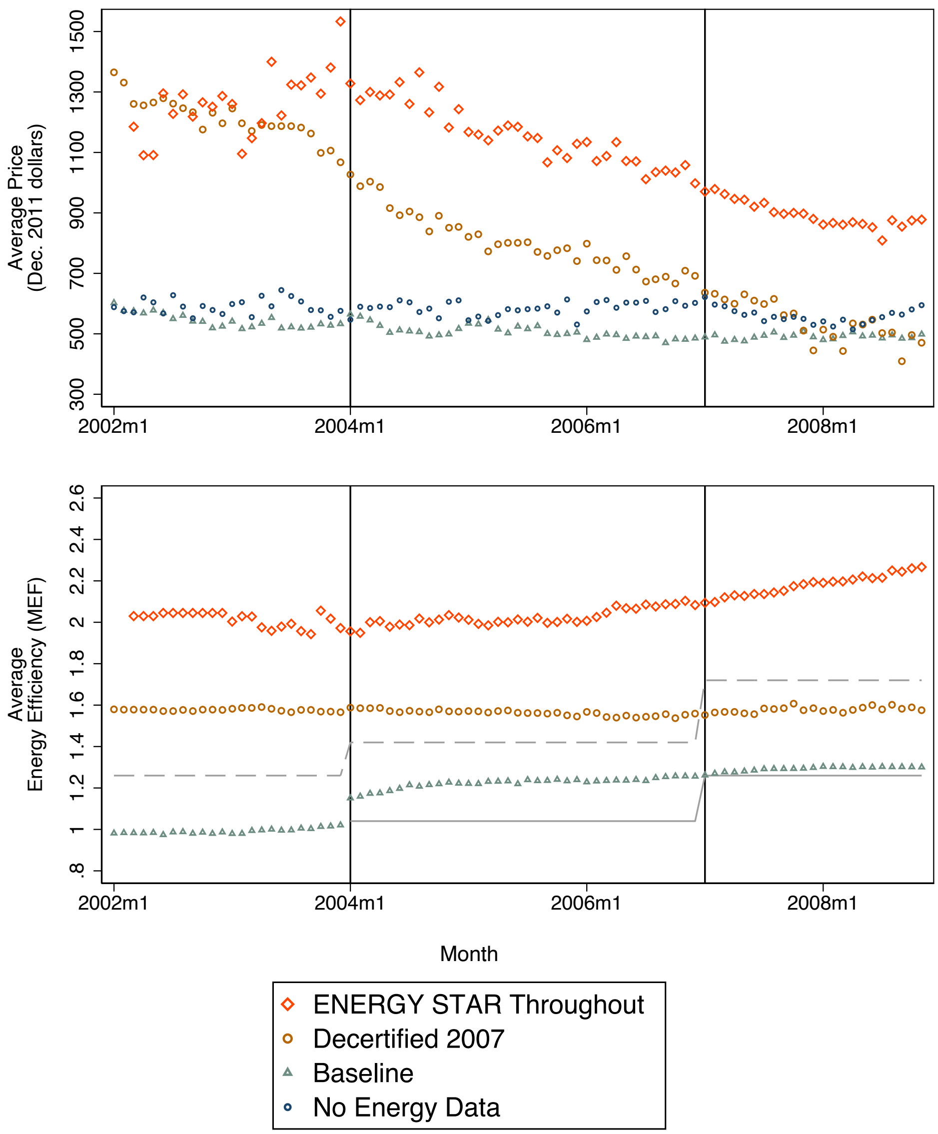

Figure 4. Efficiency and Price Over Time Differentiated Across Market Segments: This figure shows average real prices and average energy efficiency levels, using the modified energy factor (MEF), of clothes washers over time differentiated by market segment. The horizontal solid and dashed lines in the lower graph indicate the level of the federal minimum standard (solid) and ENERGY STAR criteria (dashed). This figure with the quantity weighted average real price and efficiency can be found in Appendix F.

Table 4 shows the results of the regression analysis of the change in real prices on average by market segment concurrent with the changes in minimum efficiency standard, based on Equation (1). Table 5 shows these results for the models that cannot be categorized into one of these segments due to the fact that they have no energy data. Table 6 shows the regression results for the change in MEF. We find that the change in average price of the Baseline market segment was not statistically different from zero concurrent with either standard compliance date (columns 1 and 2 of Table 4). Similarly, the real price of models for which we do not observe energy data (Table 5) do not change significantly concurrent with either standard change either. These results are robust to specifications with and without quantity weighting. To put these results in concrete terms, given the sample size of these data, with 95 percent confidence the average consumer walking into a store after the 2004 standard change would have observed prices of products in the Baseline market segment that were no more than $30 higher or $96 lower compared to prior to that standard (derived from the unweighted regression results). Then, following the 2007 standard changed, they would have been faced with Baseline product prices that were no more than an additional $29 more or $67 less. These bounds are similar, or even narrower, if the analysis is done with quantity weighting, meaning the change in the price of the average product purchased after these standard changes was even less likely to have changed by a large amount. While prices of Baseline products were not changing significantly over this period, efficiency of these products was increasing substantially. In particular, with 95% confidence, the MEF increased by 0.23 to 0.28 in 2004 (representing a percent improvement of 23-28% off of the average MEF in this market segment of 0.99 in 2002-2003). Then, in 2007 the 95% confidence interval of the average additional MEF increase was 0.04 to 0.07.

Table 4 Change in real price by market segment concurrent with change in minimum standard

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline		**Decertified 2007**		**ENERGY STAR Throughout**	
Dependent Variable: Price (Dec. 2011 dollars)	Not weighted	Quantity weighted	Not weighted	Quantity weighted	Not weighted	Quantity weighted
Standard04	-32.83	-37.15	-387.5***	-461.9***	-178.3**	-73.02
	(31.98)	(22.83)	(111.50)	(80.85)	(80.86)	(50.05)
Standard07	-19.03	25.74	-250.7***	-176.4**	-236.7***	-149.1***
	(24.35)	(26.33)	(62.05)	(73.05)	(35.37)	(45.55)
Constant	542.1***	412.1***	1,202***	1,164***	1,304***	1,094***
	(24.38)	(16.28)	(119.60)	(47.80)	(74.81)	(32.55)
Observations	6,685	5,760,079	2,040	1,510,678	4,735	4,214,139
R-squared	0.006	0.013	0.197	0.392	0.12	0.078

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

Notes: standard errors clustered by model number are presented in the parentheses.

Table 5 Change in real price concurrent with change in minimum standard for models with no energy data

	(1)	(2)
	Models with No Energy Data	
Dependent Variable: Price (Dec. 2011 dollars)	Not weighted	Quantity weighted
Standard04	-7.584	-9.978
	(23.81)	(25.20)
Standard07	-24.72	80.1
	(25.05)	(50.68)
Constant	591.9***	473.7***
	(28.31)	(18.20)
Observations	13,377	10,194,919
R-squared	0.002	0.028

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

Notes: standard errors clustered by model number are presented in the parentheses.

Table 6 Change in MEF by market segment concurrent with change in minimum standard

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline		**Decertified 2007**		**ENERGY STAR Throughout**	
Dependent Variable: MEF	Not weighted	Quantity weighted	Not weighted	Quantity weighted	Not weighted	Quantity weighted
Standard04	0.228***	0.278***	-0.0126	-0.0579	0.0369	0.0143
	(0.01)	(0.01)	(0.03)	(0.04)	(0.04)	(0.05)
Standard07	0.0697***	0.0420***	0.0106	0.013	0.154***	0.172***

	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.05)
Constant	0.993***	0.982***	1.576***	1.622***	1.999***	2.064***
	(0.01)	(0.01)	(0.02)	(0.03)	(0.03)	(0.02)
Observations	6,685	5,760,079	2,040	1,510,678	4,735	4,214,139
R-squared	0.521	0.822	0.004	0.062	0.086	0.113

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

Notes: standard errors clustered by model are presented in the parentheses.

Meanwhile, the efficiency of products offered in the Decertified in 2007 market segment did not change significantly, but the price dropped significantly in 2004 by $388 on average, and then dropped by an additional $251 in 2007. When the analysis is done with quantity weighting it indicates that the average consumer of this market segment purchased a product on average $462 less expensive following the 2004 standard, and an additional $176 less expensive following the 2007 standard.

Finally, those products that were the most efficient, those that qualified for ENERGY STAR throughout the time range of the analysis, even following both increases to the ENERGY STAR criteria analyzed, also experienced a significant drop in price of $178 in 2004 and an additional $237 in 2007. When the analysis is conducted with quantity weighting this change is not statistically significant in 2004, but is significant at a $150 price drop in 2007. At the same time that these highly efficient products were getting more affordable, the average efficiency of these products continued to increase, a change that was not significant in 2004, but was significant and on the order of a 7-8% increase over pre-2004 levels in 2007.

6 Conclusion and Policy Implications

We used market point of sales data to estimate the change in average price and efficiency of clothes washers following the change in minimum efficiency standard in 2004 and 2007, differentiated by market segment. We found that with a relatively narrow confidence interval, the average price of the Baseline market segment did not change concurrent with either the 2004 or 2007 standard change, while efficiency of these products increased by about 30% over this time period. At the same time, products that lost their ENERGY STAR certification in 2007 dropped in price to the level of the Baseline market segment but did not change in efficiency, and high-end products so efficient that they met the ENERGY STAR criteria throughout the two increases to this standard threshold experienced both a significant drop in price and increase in efficiency as well, particularly following the 2007 standard change.

These results indicate that low-income and other purchasers of low-end baseline clothes washers benefited greatly from this standard. At U.S. average electricity prices during this period of around 10 cents per kWh, someone who purchased the average Baseline product in 2007 or 2008 would have saved about $420[12] over a conservative 10-year lifetime of the product compared to if they had purchased the average Baseline model in 2002 or 2003.[13] Even if the new standard caused Baseline clothes washer prices to increase on average by even $60, which is statistically speaking unlikely, consumers of this market segment still benefited by a factor of seven from these standards. On the other end of the spectrum consumers of highly efficient clothes washers also benefited over this time period. While the MEF of this market segment of washers decreased at the 2007 standard, the kWh per year energy consumption of these washers increased slightly over this time period from 183 to 199 kWh per year (MEF is a function of both energy consumption and capacity, and so even if consumers are purchasing higher kWh per year models, they are doing so with the added benefit of increased capacity). This reflects $183 increased operating costs over a 10-year lifetime of a new washer in this market segment while at the same time the purchase price of this market segment decreased by between $150 and $415. This indicates consumers of highly efficient washers likely benefited financially during this time period, but the tradeoff is less clearly positive than for consumers of baseline products. However, benefits with respect to higher washer capacity may have also increased. Given the high share of low-income consumers that tend not to purchase high-end high-efficiency clothes washers, or who only have access to clothes washers provided by their landlord, who has no incentive to invest in a higher efficiency unit, these results suggest that the effect of this increase in minimum efficiency standards for clothes washers was progressive.

These results differ from those found in the case of CAFE standards (Davis and Knittel, 2019; Jacobsen, 2013; Levinson, 2019; Metcalf, 2019), though this is likely due to the important differences between the clothes washer and vehicle markets, which lead to differences in outcomes in models of second-degree price discrimination.

6.1 Discussion of Policy Implications

These results, coupled with previous findings regarding product quality and standards in appliance markets (Brucal and Roberts, 2019; Houde and Spurlock, 2015; Taylor et al., 2015) suggest that the quality of products provided to consumers in all market segments did not suffer significantly under the effect of standards nor was product choice substantially reduced. In the debate surrounding the implications of minimum efficiency regulation for U.S. consumers, the question has been posed as to whether improved efficiency of appliances driven by minimum efficiency standards happens at the expense of other quality characteristics. In the case of clothes washers, an often-cited concern is that more efficient front-loading clothes washers, which gained significant market share over the analyses time period, develop mold that results in unpleasant odors if not maintained with designated cleaning

[12] The average kWh per year consumption of Baseline products in our data in 2002 and 2003 was 841 and then in 2007 and 2008 was 421. That represents a reduction of 420 kWh per year.

[13] According to Consumer Reports, Manufacturers say you should get 10 years out of a new laundry appliance (Janeway, 2016).

products regularly. This analysis, however, provides some new context for this concern. The picture that tends to be painted is that the standard forced manufacturers to provide a more limited set of alternatives in order to comply with the standard, thereby forcing people to purchase a front-load washer who would not have done so otherwise. However, based on our data, 2% of the models in the Baseline market segment were front-load models in 2002-2003, and by the end of the analysis period, after the compliance dates of the two new standards, none of the models in this market segment were front-load models. Therefore, consumers of the Baseline market segment experienced a significant increase in efficiency, with no increase in price on average, and their choice was not limited by elimination of top-load washer options. Looking at the other end of the spectrum, before the first of the two-tiered standards, 100% of the models in the highest (ENERGY STAR Throughout) market segment were front-load washers, and following the two-tiered standard this market segment was then populated by both front-load (83% of models) and high-efficiency top-load (17% of models) products. Therefore, the range of options available to consumers interested in a highly efficient products actually increased concurrent with these two standard changes.

In the regulatory impact analyses conducted for the minimum efficiency standards program, the assumption made is generally that providing a more efficient set of products in compliance with a more stringent standard would cost incrementally more, and that those increased production costs would be passed on to consumers through higher product prices. The implications of our findings that clothes washer prices did not appear to increase as a result of more stringent standards, while efficiency increased significantly, suggests that this assumption may be conservative in cases where similar factors pertaining to consumer heterogeneity and market concentration align. Our results might seem counterintuitive. If the market were perfectly competitive, we would expect a more stringent energy efficiency standard to increase prices, especially for the Baseline market segment products. However, the U.S. clothes washer market is highly concentrated, and due to a variety of factors including the principal-agent problem, preferences for efficiency vary significantly across consumers. Because of this, clothes washer manufacturers have an incentive to engage in strategic pricing behavior such as second-degree price discrimination. In models of second-degree price discrimination, firms have an incentive to underprovide efficiency on the low end, and charge higher premiums on high end products. When a minimum standard is introduced in this setting, efficiency-adjusted prices decrease. This is a possible explanation for the results we document in the case of clothes washer minimum efficiency standards. Also at play are positive externalities associated with increased innovation resulting from development and production of higher efficiency products (Brucal and Roberts, 2019).

We note that our results are based on a single product. There is a need for more empirical work on the effect of standards for appliances. Such research will contribute to an understanding of both the overall and distributional impact of this policy in the appliance market, as well as the relevance of supply-side factors, such as market structure and product design and manufacturing innovation, in connection to this type of policy. This evidence regarding the significant potential benefits of standards specifically for lower-income consumers is critical, and timely, given the emphasis of the Biden-Harris administration on energy and environmental justice through Justice40 and the Presidential Memorandum on Modernizing Regulatory Review, which seeks to ensure that regulations, such and minimum efficiency standards, "appropriately benefit and do not inappropriately burden disadvantaged, vulnerable, or marginalized communities." Pertinent to this context, we find that low-income consumers were not in fact burdened or priced out of the market, but rather benefited particularly in the case of these standard changes.

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APPENDICES: Equity Implications of Market Structure and Appliance Energy Efficiency Regulation

Appendix A. Correlation between Price and Energy Consumption of Clothes Washers and Refrigerators

Because refrigerators, due to various design characteristics, tend to have two relatively distinct price points with models across the range of efficiency (see Figure A.1), we break out the correlation between price and energy consumption both separately within each of these price ranges (above the 90th percentile of price and at or below the 90th percentile of price). We also report the correlation coefficient overall across all refrigerator models. We report the correlation coefficients in a comparable way for clothes washers.

Table A.1 Correlation between real price and annual energy consumption

	Correlation Coefficient between Real Price and Annual Energy Consumption (kWh)
Clothes Washers overall	-0.3976
Clothes Washers prices above the 90th percentile of real price	-0.1918
Clothes Washers prices at or below the 90th percentile of real price	-0.4197
Refrigerators overall	0.3516
Refrigerators priced above the 90th percentile of real price	0.2067
Refrigerators priced at or below the 90th percentile of real price	0.4852

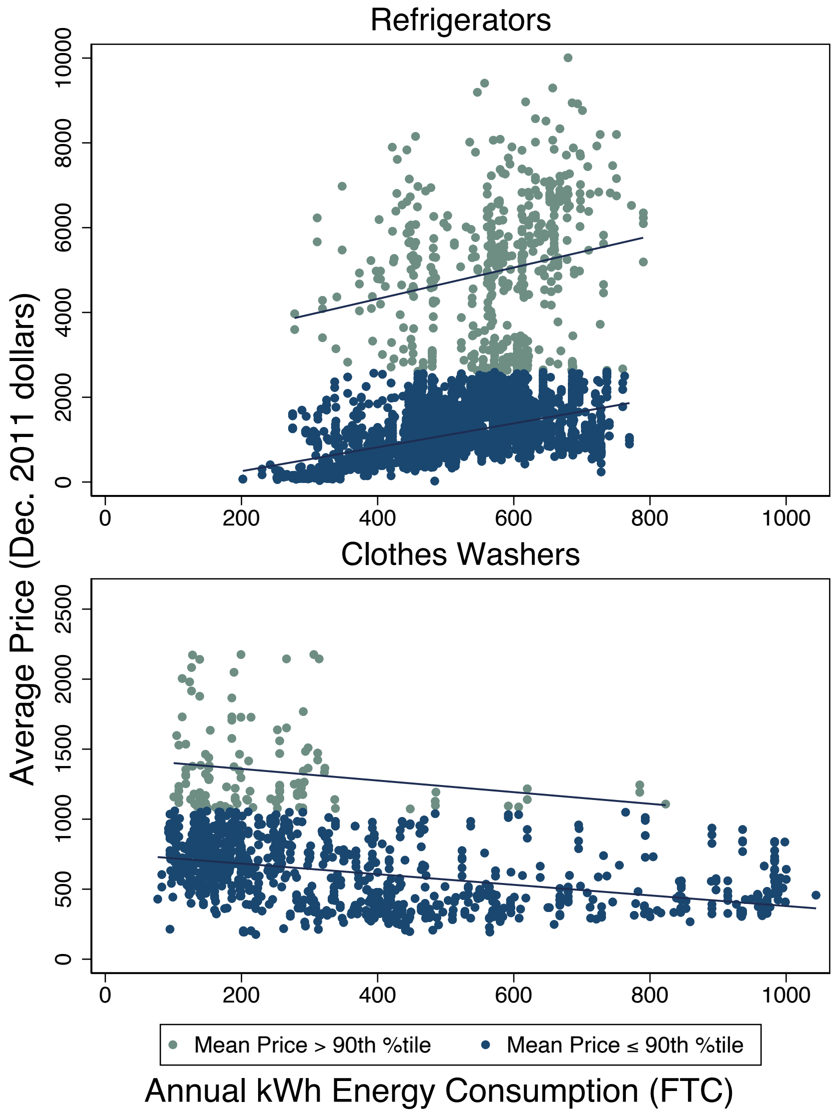

Figure A.1 Correlation between real price and annual energy consumption of refrigerators and clothes washers

Appendix B. Manufacturers and Subsidiaries in NPD

This table summarizes the manufacturers and their associated subsidiaries, as presented in Figure 1 in the paper.

Table B.1 Manufacturers and their associated subsidiaries

Manufacturer	Brand subsidiaries
Maytag	Maytag (through 2005), Amana (through 2005)
Whirlpool	Whirlpool, Estate, Inglis, KitchenAid, Roper, Maytag (starting in 2006), Amana (starting in 2006)
Electrolux	Electrolux, Frigidaire, Westinghouse, White Westinghouse

GE	GE, Ariston, Hotpoint
LG	LG
Samsung	Samsung
All Other	ASKO, Avanti Pro, Bosch, Danby, Equator Appliances, Eurotech, Fagor, Fisher & Paykel, Haier, Meile, Speed Queen, and Summit

Appendix C. Second Degree Price Discrimination Model

Below we present the generalized model of a price discriminating monopolist, and the predictions of a minimum efficiency standard change's impact on prices. In addition we discuss the implication of this strategic pricing behavior in an oligopolistic rather than monopolistic market.

We present here a reproduction, with *N* discrete types of consumers, of the key aspects of the classic monopoly price discrimination model (Mussa and Rosen 1978).

Assume consumers have unit demand for a good, here an energy consuming durable such as a clothes washer. Assume there are *N* types of consumers, ranging from low (type 1) to high (type *N*), with different levels of willingness to pay for efficiency; assume θ^k is the valuation of consumer type *k* for efficiency where $\theta^1 <\ldots< \theta^N$. Assume all types of consumers have the same positive fundamental valuation of a clothes washer *u* (e.g., they all want it to get clothes clean), independent of its level of efficiency. In equilibrium there will be *N* models of clothes washers provided by the market, indexed by *j*, which vary in efficiency (e_j) and price (p_j). Equation C.1 shows the utility of consumer type *k* for model *j*.[1]

$$U_j^k = u + \theta^k e_j - p_j \quad \text{(C.1)}$$

Suppose there are *M* consumers and $s_k \cdot M$ have valuation θ^k, where $\sum_{k=1}^N s_k = 1$. 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 $c''(e_j) \geq 0$.

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

$$\max_{e_1,\ldots,e_N} W = \sum_{j=1}^N s_j \cdot \left(u + \theta^j e_j - c(e_j)\right) \quad \text{(C.2)}$$

[1] At this point we are abstracting from the other quality characteristics or feature variation present for clothes washers. We recognize that this model is a simplification of the clothes washer market, but feel that the bulk of the intuition regarding the pricing behavior of interest is captured here.

[2] Note that we use *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 we make this explicit by indexing both by *j*.

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

Turning to the monopoly case, the monopolist picks the levels of efficiency and price (e_j, p_j) for each of the *N* models supplied in order to maximize profit and extract the maximum possible consumer surplus from all *N* types of consumers. The monopolist does not observe a consumer's type, so they cannot perfectly price discriminate.[3]

In this case they will engage in imperfect – or second-degree – price discrimination. The monopolist chooses the efficiency levels and prices of the *N* types of models they supply by maximizing their profit subject to the Individual Rationality constraints (IR_j) and Incentive Compatibility constraints (IC_{jk}) for all *j* and *k≠j* types of consumers.[4] In a separating equilibrium (i.e. $p_j \neq p_k$ and $e_j \neq e_k\ \forall\, j \neq k$) then $\theta^1 < \cdots < \theta^N$ implies that IR_1 and $ICj_{j-1}\ \forall\, j \in \{2, \dots, N\}$ are binding while all other IR and IC constraints are non-binding. The monopolist's problem therefore simplifies to that shown in Equation C.3.

$$\max_{p_1,\dots,p_N,e_1,\dots e_N} \pi = \sum_{j=1}^{N} s_j \cdot \left(p_j - c(e_j)\right) \qquad \text{(C.3)}$$
$$s.t$$
$$IR_1: u + \theta^1 e_1 - p_1 = 0$$
$$ICj_{j-1}: u + \theta^j e_j - p_j = u + \theta^j e_{j-1} - p_{j-1}, \forall\, j \in \{2, \dots, N\}$$

The solution for the unregulated monopolist, $(\bar{e}_j, \bar{p}_j)$, under second-degree price discrimination is presented in Table C.1 alongside the perfectly competitive solution. These results, as originally demonstrated (Mussa and Rosen 1978) indicate that the second-degree price discriminating monopolist distorts downward the efficiency of all but the highest type products relative the social welfare maximizing case. At the same time they charge more for a given level of efficiency compared to the welfare maximizing case. This price differential is higher for higher levels of efficiency.

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[3] If the monopolist could perfectly price discriminate, they would have an incentive to provide the social welfare maximizing level of efficiency, setting price such that each consumer would just be indifferent between purchasing and not purchasing the product. However, unless the monopolist can *ex ante* identify a consumer's type, this outcome would not be an equilibrium

[4] The IR constraints guarantee that all consumers will participate in the market, and the IC, or self-selection, constraints assure that consumer type *j* will be unwilling to purchase product type *k≠j* in equilibrium.

Table C.1. Unregulated Model Solutions

	Perfectly Competitive Solution	Monopolist Solution
$e_j, j \in 1, \dots, N-1$:	$c'(e_j^*) = \theta^j$	$c'(\bar{e}_j) = \theta^j - \frac{\sum_{k=1}^{j+1} s_k}{s_j}(\theta^{j+1} - \theta^j)$
e_N:	$c'(e_N^*) = \theta^N$	$c'(\bar{e}_N) = \theta^N$
p_1:	$p_1^* = \theta^1$	$\bar{p}_1 = u + \theta^1 \bar{e}_1$
$p_j, j \in 2, \dots, N$:	$p_j^* = \theta^j$	$\bar{p}_j = \bar{p}_{j-1} + \theta^j(\bar{e}_j - \bar{e}_{j-1})$

At this point we insert some context-specific assumptions. First, we account for the fact that a binding minimum efficiency standard $\underline{e}$ has been in place historically, requiring that $e_j \geq \underline{e}\ \forall\ j$. In addition, following recent evidence from the literature (Houde 2018), we assume that there is a subset of consumers who do not consider energy efficiency at all in their purchase decision. This implies that the lowest type consumer in this model has $\theta_1=0$, and all others have $\theta_j > 0\ \forall\ j \neq 1$.

The monopolist's solution under these assumptions is presented in Table C.2. The primary differences are that the monopolist supplies the lowest efficiency they can to the lowest-type consumer and cannot price the lowest type products based on the their degree of energy efficiency.

Table C.2. Monopolist Solution Under the Assumptions of Preexisting Regulation $(\underline{e})$ and $\theta^1 = 0$

	Monopolist Solution
e_1:	$\bar{e}_1 = \underline{e}$
$e_j, j \in 2, \dots, N-1$:	$c'(\bar{e}_j) = \theta^j - \frac{\sum_{k=1}^{j+1} s_k}{s_j}(\theta^{j+1} - \theta^j)$
e_N:	$c'(\bar{e}_N) = \theta^N$
p_1:	$\bar{p}_1 = u$
$p_j, j \in 2, \dots, N$:	$\bar{p}_j = \bar{p}_{j-1} + \theta^j(\bar{e}_j - \bar{e}_{j-1})$

We now turn to a scenario in which the monopolist faces an increase in minimum efficiency standard stringency (Besanko, Donnenfeld, and White 1988, 1987; Fischer 2005). For simplicity we assume the standard is non-binding for all efficiency levels supplied by the monopolist except the lowest. There are two possible cases: 1) the monopolist stops catering to type-1 consumers, in which case, given the assumptions outlined here, the prices of all the products in the market either remain unchanged, or increase slightly, and the products sold at pre-standard prices $\overline{p_1}$ drop out of the market, resulting in an unambiguous increase in the average prices of products sold across the entire market; or 2) the monopolist continues catering to type-1 consumers, in which case $\frac{\partial e_1}{\partial \underline{e}} > 0$; $\frac{\partial e_j}{\partial \underline{e}} = 0, \forall\ j \in \{2, \dots, N\}$; $\frac{\partial p_1}{\partial \underline{e}} = 0$; and $\frac{\partial p_j}{\partial \underline{e}} < 0\ \forall\ j \in \{2, \dots, N\}$.

In this second case, by assuming that the type-1 consumers have no positive willingness to pay for efficiency, in the face of the new standard the monopolist chooses to maintain their price point for the lowest type of products they offer, even as they are required to increase the efficiency of those products. The fact that these products are now closer substitutes for the higher efficiency products already in the market means that the monopolist must drop the prices of higher efficiency products to prevent high-type consumers switching down and purchasing the new products targeted to lower types. Whether the monopolist will choose to continue catering to the low-type consumer or not is simply a function of which option results in higher profits for them.

In the case of a perfectly competitive market on the other hand, imposing a binding standard results in either: 1) type-1 consumers dropping out of the market entirely, such that only products sold at prices $p_j^*, \forall\, j \in \{2, \dots, N\}$ remain in the market, or 2) if type-1 consumers do remain in the market and substitute up to the next product type, then $\frac{\partial p_2^*}{\partial \underline{e}} > 0$; and $\frac{\partial p_j^*}{\partial \underline{e}} = 0, \forall\, j \in \{3, \dots, N\}$. In either scenario, the perfectly competitive case predicts an unambiguous increase in the average price of products sold across the entire market and $\frac{\partial e_j^*}{\partial \underline{e}} = 0, \forall\, j \in \{2, \dots, N\}$.

The theoretical impacts of minimum quality standards on quality-differentiated markets that are oligopolistic or monopolistically competitive have also been explored. In particular, in an industry in which multiple firms face quality-dependent fixed costs and compete in quality and prices (Ronnen 1991). In this model, the introduction of a minimum quality standard causes high quality sellers to increase quality on the high end in order 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. Price competition intensifies regardless of attempts by high-end firms to alleviate it, causing prices (controlling for quality level) to drop.[5]

In addition to the consistency of the price predictions between the monopolistic and oligopolistic models, the literature on oligopolistic price discrimination discusses an additional implication of imposing a minimum quality standard in such a setting. 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 (Crampes and Hollander 1995; Ronnen 1991). They do this to alleviate the

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[5] (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 (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.

increased price competition between products imposed by the quality distribution collapse following the new standard. Realistically speaking, there is more than one quality dimension for products supplied in these markets, so the process by which firms attempt to reduce competition and increase product differentiation may be multifaceted. Therefore, increased product diversity in general may be indicative of this process.

Appendix D. Retailers in NPD Data

Table D.1 Retailers included in NPD Data

Retailers in NPD data:		"Projected" sales included for:
BJ's Wholesale Club	Meijer	Home Depot
Bloomingdale's	Nebraska Furniture Mart	Menards
Boscov's	PC Richard & Sons	Navy Exchange
Circuit City	Pamida	Queen City Appliance
Dillard's	RC Willey	REX Stores
Fortunoff	Sears	Vann's
Fred Meyer	Shopko	
Gottschalks	Target	
HH Gregg	Ultimate Electronics	
JC Penney		

Notes: "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 percent for all projected retailers combined for a given time period.

Appendix E. Estimating the Proxy MEF

We estimate the proxy MEF for those models we for which we do not observe this metric by fitting a logistic functional relationship between kWh per year energy consumption from the FTC data and the observed MEF metric from the CEC and ENERGY STAR data. This same approach was taken in Taylor, Spurlock and Yang (2015) and Houde and Spurlock (2015).

In particular we observed that the MEF is Cobb-Douglas in annual kWh energy consumption and capacity (in cubic feet). We therefore estimate the model $ln(MEF_i) = \alpha + \beta ln(kWh_i) + \gamma ln(capacity_i) + \varepsilon_i$. We then predict the values of the MEF using this model for appliance models with observed kWh and capacity data, but no MEF. The fit of the model has an R^2 of 0.84, indicating that it is a relatively good predictor for generating this proxy MEF metric.

Appendix F. Quantity weighted summary statistics tables and figures

Table F.1 Quantity weighted summary statistics for all models (both with and without energy data) and for those with no energy data

	All models			Models with No Energy Data		
	2002-2003	2004-2006	2007-2008	2002-2003	2004-2006	2007-2008
	Count			Count		
Models	664	922	937	470	555	477
Observations	5,485	10,923	10,429	3,109	5,203	5,065
Quantity Sold (Thousands)	4,107	7,534	10,039	1,855	3,210	5,130
	Mean (Std. Dev.)			Mean (Std. Dev.)		
MEF	1.09	1.56	1.89			
	0.26	0.38	0.48			
Price (2011 Dollars)	505	558	616	474	464	560
	258	305	296	145	196	309
Front Loader (%)	7	22	37	3	13	36
	Percent of Models in Market			Percent of Models in Market		
Bosch (%)	0	1	2	0	1	1
Electrolux (%)	12	14	6	11	14	12
GE (%)	12	13	12	7	3	8
LG (%)	0	5	7	0	2	1
Maytag (%)	24	12	0	36	17	0
Other (%)	1	4	29	1	5	45
Samsung (%)	0	0	3	0	1	4
Whirlpool (%)	50	52	41	45	57	29

Notes: The MEF statistics in the “All models” column reflect only those models for which we observe energy data. These include, in 2002-2003: 194 models, 2,376 observations, 2,252 thousand units sold; in 2004-2006: 367 models, 5,720 observations; 4,324 thousand units sold; and in 2007-2008: 460 models, 5,364 observations, 4,909 thousand units sold. All other statistics in those columns are derived from the full number of models and observations listed in the table.

Table F.2 Quantity-weighted summary statistics for each of the three analysis market segments

	Baseline (MEF<=1.42)			Decertified 2007 (1.42<MEF<=1.72)			ENERGY STAR Throughout (1.72<MEF)		
	2002-2003	2004-2006	2007-2008	2002-2003	2004-2006	2007-2008	2002-2003	2004-2006	2007-2008
	Count			Count			Count		
Models	158	206	164	23	71	44	23	105	253
Observations	1914	2982	1788	357	1228	455	104	1510	3121
Quantity Sold (Thousands)	1892	2185	1683	338	891	282	22	1214	2944
	Mean (Std. Dev.)			Mean (Std. Dev.)			Mean (Std. Dev.)		
MEF	0.98	1.26	1.30	1.62	1.56	1.58	2.06	2.08	2.25
	(0.06)	(0.08)	(0.05)	(0.07)	(0.10)	(0.07)	(0.05)	(0.23)	(0.22)

Price	412	375	401	1164	702	525	1094	1021	872
(2011 Dollars)	(143)	(133)	(140)	(261)	(307)	(156)	(108)	(229)	(243)
Front Loader (%)	0	0	0	61	19	1	100	87	79
	Percent of Models in Market			Percent of Models in Market			Percent of Models in Market		
Bosch (%)	0	0	0	0	0	0	9	5	6
Electrolux (%)	14	11	9	11	25	8	0	7	6
GE (%)	19	27	32	3	22	47	0	5	7
LG (%)	0	0	0	0	0	0	85	25	24
Maytag (%)	12	6	0	29	12	0	0	5	0
Other (%)	0	0	0	1	1	2	7	7	4
Samsung (%)	0	0	0	0	0	0	0	0	7
Whirlpool (%)	55	55	59	56	39	43	0	45	46

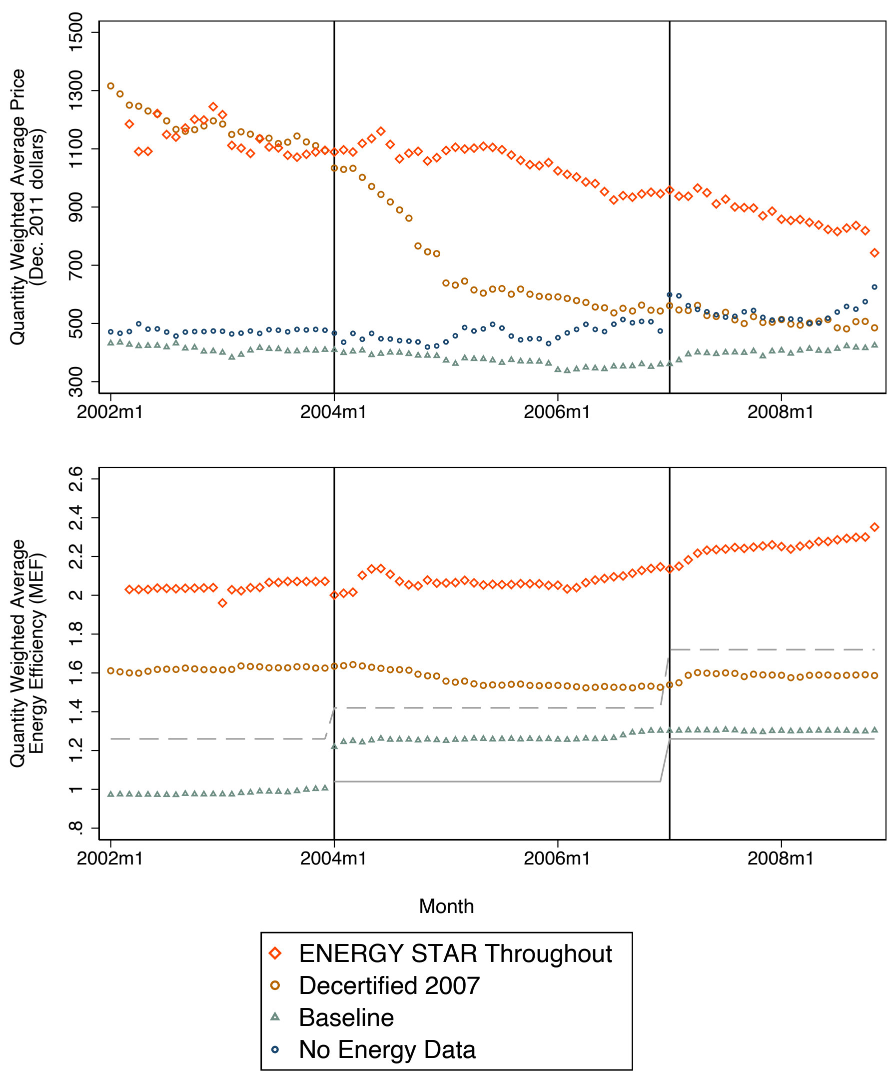

Figure F.1 Quantity-weighted Efficiency and Price Over Time Differentiated Across Market Segments

Notes: This figure shows quantity-weighted average real prices and quantity-weighted average energy efficiency levels (using the MEF) of clothes washers over time differentiated by market segment. The horizontal solid and dashed lines in the lower graph indicate the level of the federal minimum standard (solid) and ENERGY STAR criteria (dashed).

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