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Energy Efficiency and Minimum Standards: a Market Analysis of Recent Changes in Appliance Energy Efficiency Standards in the United States

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June 26, 2013

Abstract

The objective of this paper is to examine the effect of energy efficiency standards on prices and market shares of major household appliances in the United States. The household appliance market is analyzed using point-of-sale (POS) retail data of clothes washers and dryers from NPD Group. [1] Energy efficiency information for each clothes washer model was obtained from the Federal Trade Commission (FTC) appliance energy database. [2] Using these data, we conclude that energy efficiency standards had an overall negative impact on clothes washer price, and products with a mid-low efficiency rating experienced the greatest short run price drop following the January 2004 and 2007 new standard effective dates. In neither instance is there any evidence of an increase in prices of affected appliances. In both cases we analyse the price effects of the standard both relative to dryers as a counterfactual group. Additionally, we show that market shares for clothes washers shifted towards greater efficiency over the course of the period between 2002 and 2011.

Introduction

In the past decades, the U.S. Department of Energy (DOE) has dedicated great effort to reducing residential energy consumption through setting minimum energy performance standards for various household appliances. The minimum efficiency standard is determined at a level which is technologically feasible and economically justifiable. Previous studies have documented the environmental benefit and economic impact of energy efficiency standards on major household appliances. For example, Meyers, et al. (2003) estimated that consumers could save $150 billion through 2050 as a result of energy efficiency standards. While studies such as these have found that standards provide an overall benefit to society in the long run, we were interested in the market impact of standards in the short run. Under simplistic assumptions of perfect competition, the short-run impact of minimum efficiency standards should be an increase in the average market price of models still remaining in the market. The net benefit of the standard would be positive if the increase in consumer welfare from energy savings outweighed the increase in the cost of purchasing the appliance. Although it is currently not feasible to fully quantify the short run impact of energy efficiency standards on consumer welfare, a previous study has estimated a lower-bound gain/loss as a result of

[1] The NPD Group, Inc., *The NPD Group/NPD Houseworld – POS, Clothes Washers January 2002–November 2011*. Port Washington, NY. More information about NPD Group is available at: https://www.npd.com/wps/portal/npd/us/industry-expertise/home/

[2] More information about FTC's Appliance Energy Data is available on: http://www.ftc.gov/bcp/conline/edcams/eande/appliances/index.htm

clothes washer standards. The preliminary results indicate that consumer welfare loss from limiting choices of affected appliances was outweighed by consumer welfare gains from an actual price drop of more efficient appliances. This welfare calculation was made under the assumptions of perfect competition and economies of scale (Chen, et al., 2013). However, some have suggested that the assumption of perfect competition might not be entirely defensible in the context of energy consuming household durables where firms likely have market power (Fischer, 2004; Fischer, 2005; Ashenfelter, et al., 2013). To expand on this previous study, our analysis uses a similar database and estimation strategy to the report written by Chen, et al. (2013). We utilize point-of-sale (POS) data for clothes washers to empirically evaluate the impact of more stringent energy efficiency standards on market prices and market shares in order to obtain preliminary evidence as to the nature of the market for these durables, and the short run market impact of minimum efficiency standards.

In 2001, DOE adopted the 3rd federal minimum energy efficiency standard on clothes washers as part of National Appliance Energy Conservation Act (NAECA), which required residential clothes washers to be manufactured with a modified energy factor (MEF) of at least 1.04 effective on January 1st, 2004. Additionally, effective January 1st, 2007 the law required that the minimum energy efficiency threshold increased from a MEF of 1.04 to 1.26 as the second tier requirement. The criteria of Energy Star standards for clothes washers changed at the same time as minimum energy efficiency standards in both years as well. We exploit these policy changes as an exogenous intervention in the appliance market and examine how prices and market shares were affected by standards.

Data

We obtained POS data on total sales of appliances purchased in the United States from NPD Group spanning the period of 2002 to 2011, including measures of units sold and average price broken down by brand and model. NPD collects monthly POS data from major household appliance retailers aggregated at the U.S. market level. The unit price of each model is derived by dividing total revenue by total units sold. We used clothes washers in this study because this product experienced standard changes during the period for which data are available. Additionally clothes washers are among the most commonly used appliances in the U.S. household. The data also consist of a limited set of attributes for each product. For example, the clothes washer dataset provides information on washer capacity, loading type, control type and colour. The clothes washer data were filtered so that they only contain observations with identifiable brand and model numbers.

In order to identify the energy consumption of each of the models, models were matched to the Federal Trade Commission’s (FTC) assessment of energy efficiency measured as kilowatt-hours per year (kWh/y) for standard usage. We do not have this measure for all units, but we do have it for a significant majority of models in our data, 87 percent of the models with identifiable model numbers were matched to the FTC measure in the clothes washer data. However, the FTC measure of energy efficiency does not directly correspond with the U.S. Department of Energy's (DOE's) energy measure for clothes washers, and it is the DOE energy measures that are used to determine compliance with efficiency standards. For clothes washers, the energy performance metric used by DOE is Modified Energy Factor (MEF), defined as cubic feet per kWh per cycle. In calculation of the MEF used by DOE, the total kWh measure accounts for the machine electrical energy, water heating energy and moisture removal energy, which the FTC measure does not fully account for.

Since the FTC energy measures cannot be directly converted to the DOE's energy performance metrics, we are not able to identify which specific models would be banned due to the standards. However, we use the FTC measure of efficiency (kWh/y) to classify all the models into different efficiency bins and study the price change around the standard effective dates in each bin. The FTC energy measure is an important indicator of efficiency rating to distinguish among different models and is posted on appliances to inform consumers of the energy ratings of potential purchases.

Price and Market Share Movement over Time

The average price and average market share of clothes washer units sold are plotted in Figures 1 and Figure 2, respectively. The figures show the overall change in prices and market shares by efficiency ratings for clothes washers from 2002 to 2011. These figures were generated using all models for which the FTC energy measure is available. Five efficiency bins were assigned based on quintiles of the entire efficiency range of products sold from 2002 to 2011. All prices were adjusted for inflation using the GDP deflator and reported in 2010 dollars, and the average prices shown in each efficiency bin were weighted by quantities sold in that same efficiency group.

In Figure 1, we can see that overall raw clothes washer prices in each efficiency bin decreased from 2002 to 2011. For washers that fell into mid- low efficiency bins, their prices dropped even more precipitously than washers with higher efficiency ratings, especially when a new standard came into effect in both 2004 and 2007.

In Figure 2, we first notice that the clothes washers' efficiency performance varied a lot from year to year, but this variation appeared to lessen over time. In addition, the market share distribution against efficiency level in every year showed a bimodal distribution, which means that there were two peaks in the market share distribution, and these two peaks were located at opposite ends of the efficiency spectrum. This shape implies that the highest market shares of clothes washers were concentrated among models with both the highest efficiency and the lowest efficiency available in that year regardless of the standards. In other words, the clothes washer market generally seems to have consisted of two broad types of consumers, one with higher preference for energy efficiency and the other with lower preference for energy efficiency. The implication of this is discussed further in the conclusion.

When comparing the shape of the market share distribution between the standard effective year and the year prior to that (marked in solid lines in Figure 2), a considerable number of inefficient washers disappears from the market and the distribution shifts toward more efficient washers at the time the new standards came into effect. Energy efficiency standards not only improved the average energy consumption of washers, they also reallocated the market share of more and less efficient washers. In 2003, clothes washers with the lowest efficiency rating dominated almost half of the market; while starting in 2006, more and more consumers shifted toward more efficient washers. After 2007, more high-efficiency washers were sold than relatively low-efficiency washers, and the market has become largely dominated by relatively high-efficiency washers by 2011.

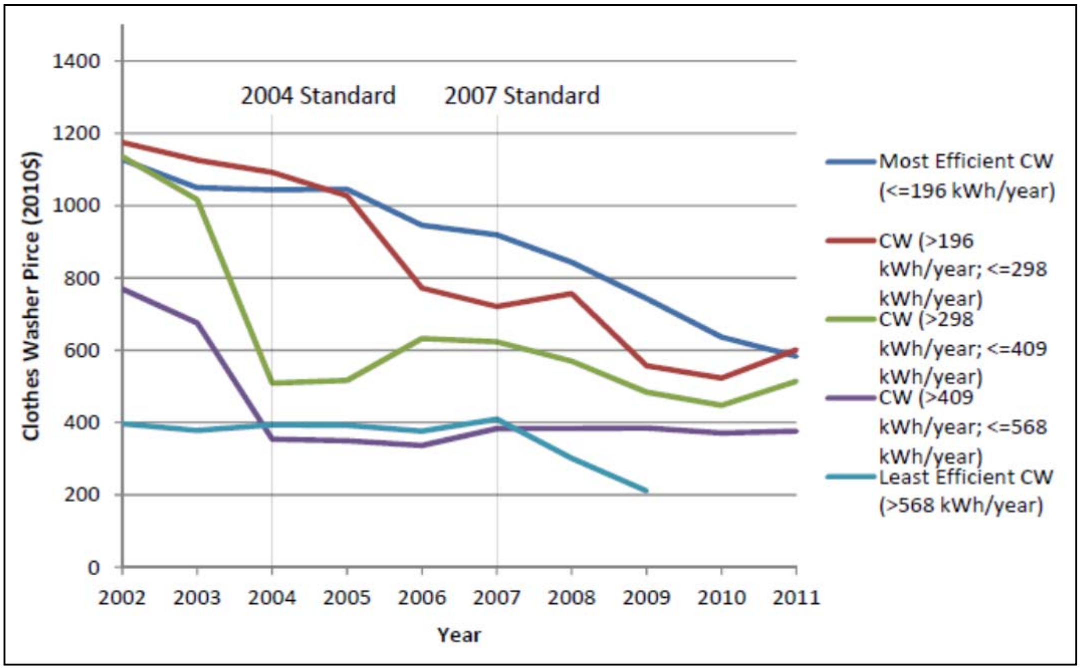

Figure 1. Clothes Washer Price Trend by Efficiency Levels from 2002 to 2011

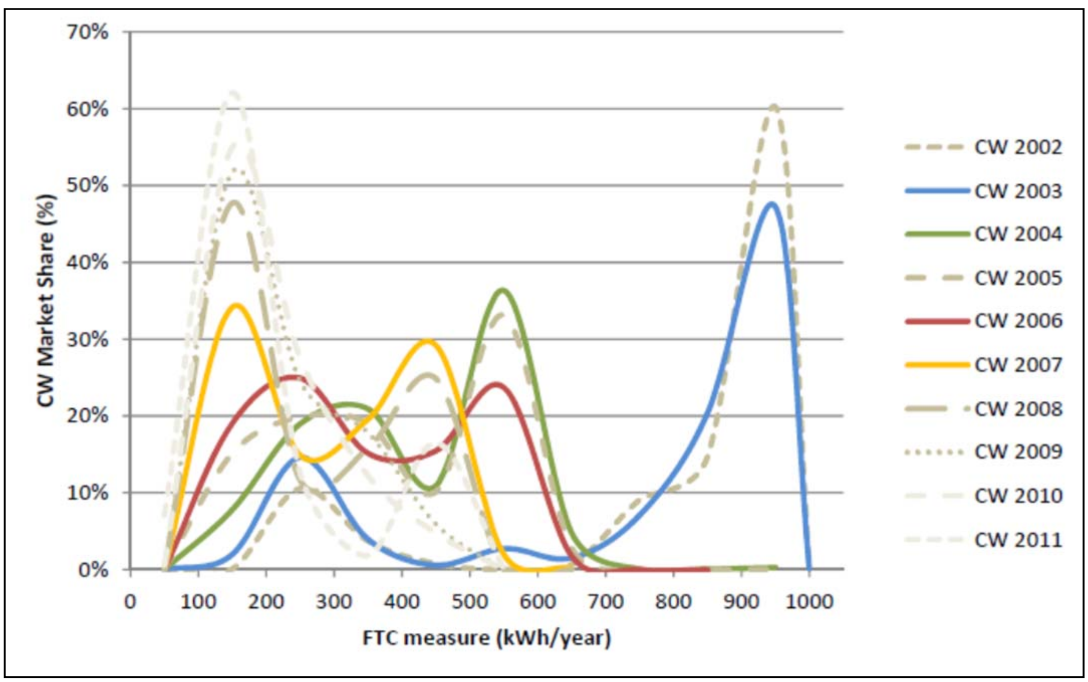

Figure 2. Clothes Washer Market Share Distribution against Efficiency Level from 2002 to 2011

Price Impact Estimation of Standards in the Short Run

In the previous section, we've shown historical raw price trends for clothes washers to visualize the price change surrounding their standard effective dates. However, in order to truly evaluate the price impact attributed to standards, we need to utilize a more rigorous approach. The implementation of energy efficiency standards usually is associated with changes in the mix of models provided in the market, which changes the set of product attributes available to consumers, and sometimes there are tradeoffs between energy efficiency gains and these product attributes (Greening, et al., 1997). Although some attributes of washers such as energy efficiency, capacity, soil sensors and spin speed arguably have improved as a result of standards, other features may have become less desirable, like the longer duration of the washing cycle and poorer cleaning performance. We use regression models with and without fixed-effects to estimate within-model as well as overall changes in prices for clothes washers. In the following sections, we detail the model specification and the application of these regression models to our clothes washer dataset. Before exploring the quantitative results, however, we first present graphical evidence of the within-model average impact of the standards on prices of clothes washers.

In order to show the within-model price changes graphically for clothes washers, we provide Figure 3. The average within-model price trend for dryers (Figure 4) is included here as a counterfactual group to represent a general price trend of similar household appliances over the same period of time that were not affected by the standards. It is worth noting that dryers are not an ideal control group in this context because arguably dryers and clothes washer are complimentary goods, and so their price trends are not mutually independent. However, it is likely that an observed change in the price of clothes washers that is statistically different from that of clothes dryers is likely to underestimate the true effect on the price of clothes washers, as the prices of these two products should be positively correlated, if anything. The results using dryers as a control, however, should be interpreted carefully because of the fact that these two product markets are not independent. The graphs were generated by regressing price on model-specific fixed effects as well as a dummy for each time period in the sample. Using a technique common in the event study literature, the coefficients on each time dummy are plotted over time for each appliance. These coefficients are the overall average within-model change in price between each time period and the base period (January 2002). The circled dots are the average price change relative to January 2002 and the solid lines represent plus and minus 2 standard errors. The two red vertical lines represent the dates when more stringent standards went into effect for clothes washers, January 2004 and January 2007 respectively. We can see that within-model real prices of these two appliances show a downward trend over the sample period, and on average the within-model prices for clothes washers dropped at the standard dates. The within-model prices of dryers did not appear to change at the dates for which the standards changes for clothes washer. Moreover, we also observed a steeper downward price trend for clothes washers following the standard date relative to before the standard as compared to dryers, the control group. Therefore, it appears that efficiency standard changes lead to a short-run drop in within-model price on average for affected appliances. This drop could be in the form of either a level drop and/or a downward trend-break. In the next section, we turn to the regression analysis to quantify this result.

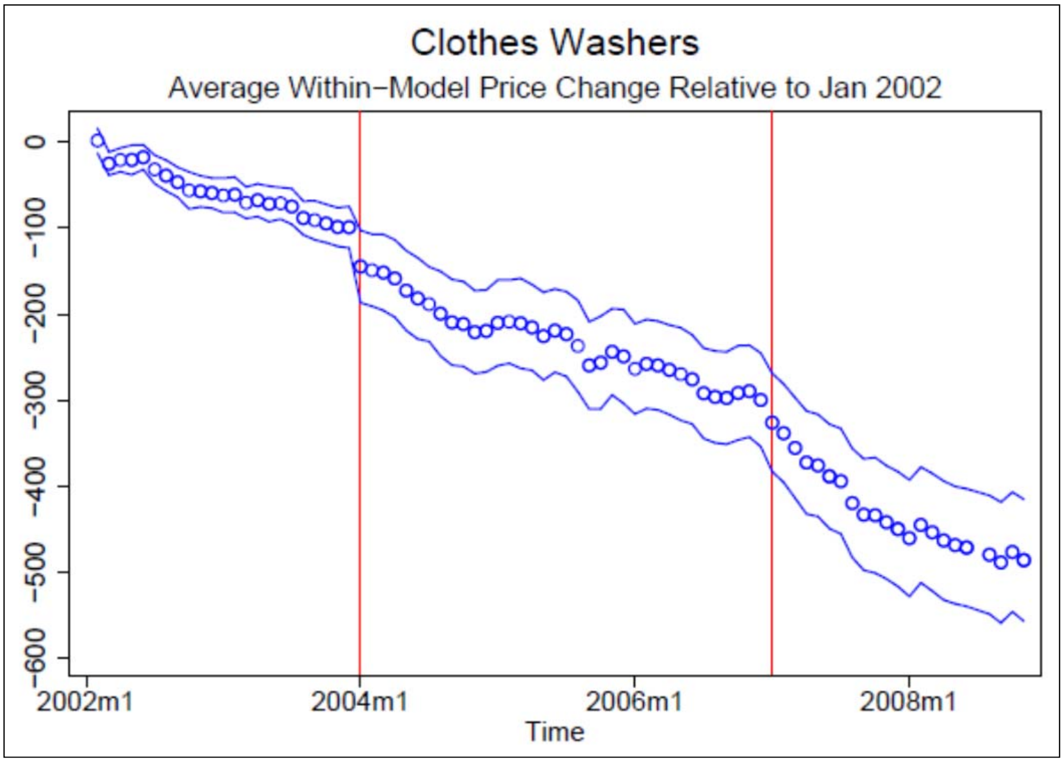

Figure 3. Average Within-Model Price Change Relative to January 2002 for Clothes Washers

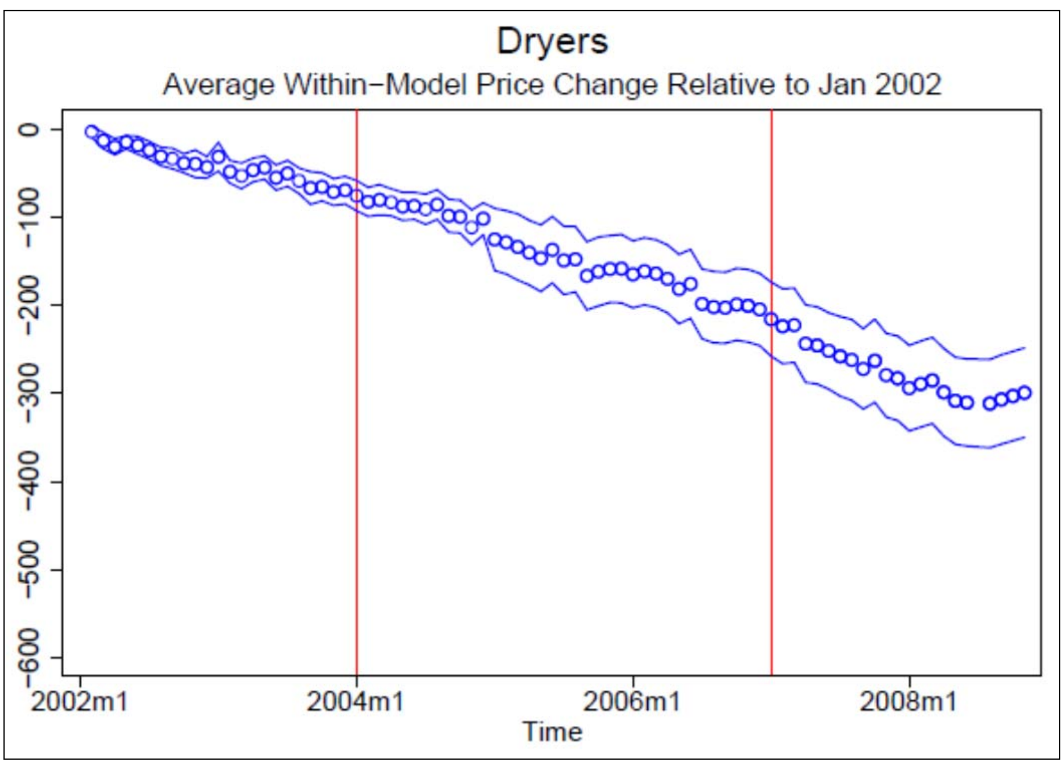

Figure 4. Average Within-Model Price Change Relative to January 2002 for Dryers

Model Specification

We implemented two types of regression models to examine the price impact of standards on clothes washers. The first model is a linear regression with fixed effects. Fixed effects models are used to explore the relationship between the dependent variable (price) and independent variables that have within-model variation. This regression approach includes fixed effects for each clothes washer model, along with a linear time trend, a policy shock dummy, and an interaction term between the time trend and policy dummy to allow for a trend break. The inclusion of fixed effects controls for all time-invariant model-specific features of products. Using this type of analysis enables us to explain how within-model prices change right after the standard effective date and estimate the magnitude of the change. We also used a linear regression without fixed effects. As opposed to the fixed effects model, a simple linear model captures the relationship of the dependent variable (price) and independent variables across all models for clothes washers. This type of analysis allows us to examine the impact of standards on the overall average price in the product market.

Regression Model Application

To apply these model specifications, we first separated the analysis into two categories: (1) overall regressions pooling all models, and (2) efficiency-level regressions with clothes washer models broken down into five efficiency groups. As mentioned at the beginning of the paper, the focus of this study is to measure the short-term price impact of the 2004 and 2007 standards on clothes washers. Hence, the regressions only include models purchased one year prior to and one year after the standard change.

Overall Regression Specification

In the case of the pooled regressions, the regression used to examine the January 2004 standard for clothes washers covers washer models sold between January 2003 and December 2004; the regression used to examine the January 2007 standard for clothes washers covers washer models sold between January 2006 and December 2007. The length of time for each analysis was chosen so that it focuses on the short-term price impact of standards and prevents results from being confounded with other policy changes, such as other federal standard changes or Energy Star criteria changes.

We fit the first set of regressions on product prices and various independent variables for clothes washers to study the impact of standards on their prices. However, other unobserved factors that changed concurrently with these standard changes may have also affected product prices. These unobserved factors might include, but are not limited to, changes in energy prices, the collapse of the housing market, and prolonged downturn in the aggregate economy. It could also include changes to the data mix provided by NPD, as the mix of retailers included in the data did change over time. To minimize the impact of microeconomic and data fluctuation, we fit a second set of overall regressions using clothes dryers as a control group with a Difference-in-Difference strategy so that the coefficient is the price change relative to the price change of clothes dryers. Hence, we present two set of results for the overall regressions: (1) a set only including clothes washer models to estimate the effects of the clothes washer standard changes, and (2) another set including dryer models in each regression as a control group.

The effect of the policy itself is estimated with a dummy variable to capture the effect around the time of the policy change. We also included an interaction term between the policy shock dummy variable and the time trend variable. This is because the policy change could have two potential impacts on price: a level-change in price between the pre-period and post period, and/or a break in the price trend (i.e. prices could begin to drop more or less quickly as a result of the standard).

The standard model specifications for the overall regressions have the forms:

- Non-fixed effect model

$$p_{it} = \alpha + \delta T_i + \beta_1 Trend_t + \beta_2 Standard_{it} + \beta_3 (Trend * Standard)_{it} + \beta_4 (T * Trend)_{it} + \beta_5 (T * Standard)_{it} + \beta_6 (T * Trend * Standard)_{it} + \varepsilon_{it}$$

- Fixed effect model

$$p_{it} = \alpha + \gamma_i + \beta_1 Trend_t + \beta_2 Standard_{it} + \beta_3 (Trend * Standard)_{it} + \beta_4 (T * Trend)_{it} + \beta_5 (T * Standard)_{it} + \beta_6 (T * Trend * Standard)_{it} + \varepsilon_{it}$$

where *Trend* is a time trend variable increasing by one unit each month through the sample, *Standard* is a dummy variable equal to 0 prior to the standard effective date and equal to 1 after the effective date, *T* is a treatment dummy variable equal to 1 if the appliance faces a standard change and equal to 0 if the appliance is the control appliance (clothes dryers in this case), and γ_i denotes the fixed effects. The index *i* refers to the unit of observation (an individual appliance model), and *t* refers to the monthly time period. The treatment dummy variable, *T*, is only included to estimate the additional impact of standards on clothes washers relative to dryers, the control group. When estimating the overall regression with no fixed effects, the model specification is similar to the fixed effects regressions except dropping the fixed effects, γ_i and adding *T* dummy variable to capture the average overall price of clothes washers as compared to the omitted product (dryers in this case).

Efficiency-Level Regression Specification

Besides learning the overall price impact on all models, we are also interested in knowing whether the price impact would differ by efficiency group. Preliminary evidence from the historic POS data for clothes washers has shown that product with mid-low efficiency rating potentially experienced relatively bigger price drops after the standards took effect, particularly at the 2004 standard change (Figure 1). Here we fit both the non-fixed effect and fixed effect regression models to the data surrounding the 2004 and 2007 clothes washer standards with five efficiency grouping variables and compare the magnitude of the price effect across efficiency groups to see if the price change in lower efficiency groups is statistically larger than those in higher efficiency groups or vice versa. These regressions for the efficiency-level specific effects continue to focus on the short-run effects and only include models purchased one year prior to and one year after the standard change, similarly to the overall regressions.

Analogous to the overall regression, in order to avoid possible confounding factors that change concurrently with the standard changes, we fit a second set of regressions not only to clothes washers but also including dryer models as controls. Since there is no FTC data available for dryers, dryer models were included in the regression without assigning efficiency levels. Therefore, the coefficient on each efficiency group variable in the regression is the washer price change within that efficiency group relative to the overall price change of all clothes dryers. In addition to the efficiency group variables, the FTC measure is added to the fixed effects regression with no control group included because this measure does change over time for a handful of models and the FTC measure is not available for dryers. These regressions included all models for which the FTC measure is available for clothes washers.

The efficiency-level specific regression models can then be specified as follow:

- Non-fixed effect model

$$p_{it} = \alpha + \beta_1 Trend_t + \beta_2 Standard_{it} + \beta_3 (Trend * Standard)_{it} + \sum_{j=1}^{5} \theta_j Eff.Group_{ji} + \sum_{j=1}^{5} \tau_j \left(Eff.Group_j * Trend\right)_{it} + \sum_{j=1}^{5} \varphi_j (Eff.Group_j * Standard)_{it} + \sum_{j=1}^{5} \rho_j (Eff.Group_j * Trend * Standard)_{it} + \varepsilon_{it}$$

- Fixed effect model

$$p_{it} = \alpha + \beta_1 Trend_t + \beta_2 Standard_{it} + \beta_3 (Trend * Standard)_{it} + \gamma_i + \sum_{j=1}^{5} \tau_j \left(Eff.Group_j * Trend\right)_{it} + \sum_{j=1}^{5} \varphi_j (Eff.Group_j * Standard)_{it} + \sum_{j=1}^{5} \rho_j (Eff.Group_j * Trend * Standard)_{it} + \varepsilon_{it}$$

where *Trend* is a time trend variable increasing by one unit each month through the sample, *Standard* is a dummy variable equal to 0 prior to the standard effective date and equal to 1 after the effective date, $Eff.Group_j$ is a dummy variable equal to 1 if the clothes washer model falls into the efficiency group *j* and equal to 0 otherwise where j={1,2,3,4,5], and γ_i denotes the fixed effects. The index *i* refers to the unit of observation (model), *t* refers to the monthly time period, and *j* refers to different efficiency group with 1 as the most efficient group and 5 as the least efficient group. Since the fixed effects model is measuring the relationship between price and time-variant variables within each model, time-invariant variables like $Eff.Group_{ji}$ were dropped in the fixed effects regressions.

Regression Model Results

The dependent variable in all the following regressions was the unit price; hence the interpretation of the coefficients on each independent variable is simply in dollar value terms.

Overall Regression Results

Results from the overall regressions examining the price impact of the 2004 and 2007 standards on clothes washers are reported below. Table 1 presents the regression results with no fixed effects; and Table 2 presents the regression results with fixed effects.

In Table 1, we focus more on interpreting the coefficient results from regressions (2) and (4) because they attempt to limit the confounding effect of background price noise and other unobservable changes by including clothes dryers as a control group. Recall that the magnitudes of these coefficients are likely a lower bound on the true effect on clothes washer prices, because clothes washer and dryers are complimentary goods. When a control group was added, we see that on average non-weighted prices of these appliances did not change significantly during this time period, as the coefficient on the time trend is not significant. At the time of the standard change, the average overall dryer price only experienced statistically significant level increase ($43.47) at the time of the 2004 standard. On the other hand, the price of dryers experienced a trend break around the time of the 2007 standard, rising on average $4.62 more quickly per month after January 2007. To explain the price impact on the affected product, we look at the additional level change and trend-break during and after the standard year as compared to dryers. There was no statistically significant change in the average market price of washers relative to dryers at the time of the 2004 standard change. At the time of the 2007 standard change, the average market price of clothes washers dropped marginally significantly, at a magnitude of $29.49, although this drop is not significant relative to dryers. There was no indication at the time of either standard that there was a statistically significant break in trend in average market prices of clothes washers.

Table 1. Overall Regression Results with no Fixed Effect

	2004 Standard Change		2007 Standard Change	
	(1)	(2)	(3)	(4)
Dependent Variable: Price	No Controls	Dryers as Controls	No Controls	Dryers as Controls
T		146.7***		161.9***
		(34.94)		(35.93)
Trend		-0.418		1.219
		(1.506)		(1.376)
Standard		43.47**		1.271
		(18.11)		(10.46)
Trend * Standard		2.877		4.621**
		(2.447)		(2.176)
T * Trend	2.043	2.461	0.103	-1.116
	(2.548)	(2.959)	(2.027)	(2.449)
T * Standard	40.83	-2.635	-29.49*	-30.76
	(35.64)	(39.96)	(16.66)	(19.66)
T * Trend * Standard	-1.872	-4.749	2.651	-1.970
	(4.010)	(4.696)	(2.885)	(3.612)
Constant	614.2***	467.5***	703.3***	541.4***
	(31.96)	(14.15)	(31.41)	(17.48)
Model Fixed Effects	N	N	N	N
Observations	3,637	7,283	4,793	10,655
R-squared	0.005	0.068	0.001	0.044

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

The results from Table 1 indicate that the average price of products available in the marked did not change significantly in general other than a marginally significant drop in price on average in 2007. However, if we want to see what happens to prices of models existing on the market at the time of standard we must control for model-specific characteristics. This is accomplished using the fixed effects analysis. Once again, we focus our discussion of the results to the case when the dryer control group was included, which are regressions (2) and (4) in Table 2.Our coefficients of interest are the coefficients on "*T*Standard*" and "*T*Standard*Time trend.*" The estimated results show that within-model prices for clothes washers dropped $34.9 relative to clothes dryers at the 2004 standard date. Furthermore, within-model prices had a more rapid monthly incremental decline in price for clothes washers than dryers after the 2004 standard date by $3.47 per month. In contrast to this, in 2007 there was no statistically significant within-model level change in clothes washer prices beyond that of dryers, although when dryers are not included within-model clothes washer prices dropped significantly by $13.23 at the time of the 2007 standard. Additionally, there was a statistically significant downward trend-break for clothes washers in 2007 indicating that within-model prices dropped more quickly for clothes washers compared to dryers by $4.64 per month following the 2007 standard.

Table 2. Overall Regression Results with Fixed Effect

	2004 Standard Change		2007 Standard Change	
	(1)	(2)	(3)	(4)
Dependent Var: Price	No Controls	Dryers as Controls	No Controls	Dryers as Controls
Trend		-3.600***		-5.159***
		(0.548)		(0.648)
Standard		-1.683		-2.954
		(4.290)		(4.202)
Trend * Standard		0.413		-2.438**
		(0.974)		(0.984)
T * Trend	-4.342***	-0.743	-5.754***	-0.595
	(0.815)	(0.976)	(0.835)	(1.056)
T * Standard	-36.58***	-34.90***	-13.23**	-10.28
	(11.16)	(11.87)	(6.383)	(7.639)
T * Trend * Standard	-3.054***	-3.468**	-7.079***	-4.641***
	(1.098)	(1.461)	(1.371)	(1.687)
Constant	739.1***	634.3***	799.2***	714.6***
	(11.36)	(5.985)	(9.330)	(5.389)
Model Fixed Effects	Y	Y	Y	Y
Observations	3,637	7,283	4,793	10,655
R-Squared	0.235	0.209	0.319	0.300
Number of Models	418	736	431	959

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

Efficiency-Level Regression Results

We divided product efficiency into quintiles to form five efficiency groups. However, products with the lowest efficiency level sold prior to the standard year may become obsolete after the standard, and brand new models with better energy performance may emerge in the market after the standard effective date. In order to be as consistent as possible, models were assigned a unique categorization in the following way: efficiency quintiles were calculated using the efficiency distribution of all models appearing in the data the year prior to the standard. If the models appeared in the data in the year before a standard, they were assigned an efficiency group based on these quintiles. On the other hand, for those models that didn't exist in the data before the standard, they were assigned an efficiency group determined based on the efficiency quintile of all models sold after the standard. The efficiency categorization is given to each model based on its matched FTC model instead of the model number reported by NPD. In many cases, especially around the standard changes, we found new models appeared in the market with only one letter difference in model series number from their previous version of the model in the NPD data. When we matched those to the FTC energy measure, they tended to match to the same FTC model number as well. They essentially have the same basic form of features as the previous version of model except some improvements internally to efficiency performance. In the efficiency-level regression analysis, we are treating those "new models" which appeared in the data after the standard equivalent to their previous version and categorized them in the same efficiency bin as their counterpart model based on the same FTC model number they match to. In this case we are keeping the efficiency categorization more consistent by relying on the basic features of a model and those features' pre-standard efficiency level in order to define the efficiency-based stratification of products available on the market.

We ran the efficiency-level regressions both with and without fixed effects. Similar to the analysis looking at the average price effects, the efficiency-level regressions examined the impact of 2004 and 2007 standards on clothes washers. Table 3 presents the regressions looking at the differential impact of the standard on the prices of models in five efficiency levels when no fixed effects are used, while Table 4 looks at the within-model price changes for models across these efficiency groupings using fixed effects. Tables 3 and 4 present two sets of regression results for the two standard events we are interested. One set of the results show regression estimates with no control group, and the other set of the results show regression estimates with dryer models added to each regression as a control group. The interpretation of the coefficients in these regressions is similar to the pooled regressions, and the coefficients of interests are coefficients on "$Group_j$*Standard*" and "$Group_j$*Standard*Trend*".

We look first at the results presented in Table 3. There was a no statistically significant trend in prices of clothes washers or dryers leading up to the 2004 standard change. This is also true leading up to the 20067 standard change for dryers and all washer groups except the second-highest efficiency group, which was experiencing a downward average trend in within-model prices of $17.14 per month relative to dryers. At the time of the 2004 standard change, none of the three highest efficiency groups experienced a level change in prices. On the other hand the lowest efficiency group (Group 5) experienced a significant drop in prices of $63.25, and the second-lowest efficiency group (Group 4) experienced a significant drop in prices of $80.12 relative to dryers at the 2004 standard change. Additionally, the lowest and the highest efficiency groups experienced statistically significant downward breaks in trend at the time of the 2004 standard, dropping $8.20 and $15.92 more quickly per month relative to dryers following the standard change, respectively. Finally, at the time of the 2007 standard change, only the lowest efficiency group experienced a statistically significant drop in price level on average ($44.43) and downward break in average price trend ($6.91 per month) relative to dryers.

We now discuss the results from the fixed effects regressions presented in Table 4, once again focusing on regressions (2) and (4) which show the results relative to dryers. Here we see that within-model prices of dryers, as well as clothes washers, tended to trend downward over time. The within-model prices of the highest efficiency groups tended to trend downward more quickly for clothes washers, particularly at the time of the 2007 standard change. At the time of the 2004 standard change, the within-model prices of the two lowest efficiency groups dropped on average relative to dryers once again.

Table 3. Efficiency-Level Regression Results with no Fixed Effect

	2004 Standard Change		2007 Standard Change	
	(1)	(2)	(3)	(4)
Dependent Var: Price	No Controls	Dryers as Controls	No Controls	Dryers as Controls
Trend		-0.418		1.219
		(1.508)		(1.377)
Standard		43.47**		1.271
		(18.14)		(10.47)
Trend * Standard		2.877		4.621**
		(2.450)		(2.178)
Group 1 (Most Efficient)	644.1***	737.5***	462.3***	537.3***
	(130.2)	(112.7)	(87.34)	(72.58)
Group 2	57.21	150.6*	414.6***	489.6***
	(109.5)	(88.09)	(88.74)	(74.24)
Group 3		93.38		74.98
		(67.75)		(54.29)
Group 4	-85.44	7.939	-79.03	-4.042
	(81.51)	(49.26)	(83.40)	(67.80)
Group 5 (Least Efficient)	-87.76	5.625	-203.1***	-128.1***
	(71.14)	(29.18)	(56.42)	(28.93)
Group 1 * Trend	4.265	4.682	-6.986	-8.206
	(7.629)	(7.761)	(4.870)	(5.052)
Group 2 * Trend	2.306	2.724	-15.92***	-17.14***
	(6.241)	(6.407)	(4.266)	(4.476)
Group 3 * Trend	-4.804	-4.386	4.841	3.622
	(4.613)	(4.844)	(4.376)	(4.581)
Group 4 * Trend	-3.300	-2.882	-4.915	-6.134
	(2.024)	(2.521)	(3.796)	(4.032)
Group 5 * Trend	-0.665	-0.247	1.584	0.364
	(1.830)	(2.368)	(1.363)	(1.936)
Group 1 * Standard	-38.25	-81.72	-20.19	-21.46
	(84.51)	(86.26)	(35.32)	(36.78)
Group 2 * Standard	48.34	4.871	-10.40	-11.67
	(66.78)	(69.07)	(41.98)	(43.20)
Group 3 * Standard	94.16	50.69	-35.77	-37.04
	(73.63)	(75.68)	(22.48)	(24.76)
Group 4 * Standard	-36.65*	-80.12***	28.82	27.55
	(21.93)	(28.43)	(25.17)	(27.22)
Group 5 * Standard	-19.78	-63.25*	-43.15**	-44.43**
	(31.71)	(36.47)	(19.28)	(21.91)
Group 1 * Trend * Standard	-13.04	-15.92*	1.191	-3.430
	(9.028)	(9.336)	(6.226)	(6.586)
Group 2 * Trend * Standard	-5.029	-7.906	5.180	0.559
	(7.488)	(7.863)	(6.262)	(6.619)
Group 3 * Trend * Standard	-0.387	-3.264	-2.055	-6.675
	(6.503)	(6.936)	(6.489)	(6.834)
Group 4 * Trend * Standard	3.188	0.311	0.446	-4.174
	(2.959)	(3.837)	(3.736)	(4.319)
Group 5 * Trend * Standard	-5.317*	-8.195**	-2.291	-6.912**
	(3.057)	(3.913)	(2.579)	(3.372)
Constant	560.9***	467.5***	616.4***	541.4***
	(66.39)	(14.17)	(51.48)	(17.50)
Model Fixed Effects	N	N	N	N
Observations	3,073	6,719	4,493	10,355
R-squared	0.501	0.410	0.364	0.253

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

Table 4. Efficiency-Level Regression Results with Fixed Effect

	2004 Standard Change		2007 Standard Change	
	(1)	(2)	(3)	(4)
Dependent Var: Price	No Controls	Dryers as Controls	No Controls	Dryers as Controls
Trend		-3.600***		-5.159***
		(0.548)		(0.648)
Standard		-1.683		-2.954
		(4.285)		(4.204)
Trend * Standard		0.413		-2.438**
		(0.973)		(0.984)
Group 1 (Most Eff) * Trend	-6.720*	-3.105	-9.077***	-3.957*
	(3.824)	(3.832)	(2.144)	(2.248)
Group 2 * Trend	-4.161*	-0.170	-11.40***	-6.138**
	(2.229)	(2.189)	(2.250)	(2.382)
Group 3 * Trend	-3.042***	0.699	-5.331***	0.281
	(0.835)	(0.953)	(1.423)	(1.618)
Group 4 * Trend	-4.912***	-1.858*	-2.378***	2.936***
	(0.995)	(1.068)	(0.825)	(1.025)
Group 5 (Least Eff)* Trend	-1.718	1.693	-2.077**	3.082**
	(1.141)	(1.245)	(1.033)	(1.218)
Group 1 * Standard	-30.83	-28.26	2.391	4.781
	(28.63)	(28.89)	(16.17)	(16.68)
Group 2 * Standard	-27.87	-20.48	-7.496	-9.252
	(36.17)	(36.42)	(19.34)	(19.24)
Group 3 * Standard	-41.34***	-14.38	-23.93*	-26.78**
	(15.04)	(11.87)	(13.12)	(12.20)
Group 4 * Standard	-95.64***	-90.51***	-8.402	-6.722
	(27.47)	(27.50)	(8.242)	(9.000)
Group 5 * Standard	-60.06***	-34.64**	-25.63**	-22.66*
	(17.66)	(15.32)	(12.48)	(13.15)
Group 1 * Trend * Standard	-6.157	-6.582	-5.921**	-3.450
	(4.446)	(4.516)	(2.807)	(2.977)
Group 2 * Trend * Standard	-3.808	-4.566	-9.932**	-7.714*
	(2.972)	(3.051)	(3.861)	(4.014)
Group 3 * Trend * Standard	-1.821	-2.378	-4.639*	-2.423
	(1.235)	(1.567)	(2.607)	(2.910)
Group 4 * Trend * Standard	0.741	0.872	-4.382***	-2.126
	(1.142)	(1.480)	(1.631)	(1.878)
Group 5 * Trend * Standard	-1.981	-1.962	-4.143*	-1.706
	(1.465)	(1.750)	(2.190)	(2.398)
FTC kWh/year	-0.121**		1.119*	
	(0.0526)		(0.571)	
Constant	835.8***	636.0***	427.9**	713.7***
	(36.10)	(6.454)	(191.6)	(5.101)
Model Fixed Effects	Y	Y	Y	Y
Observations	3,073	6,719	4,493	10,355
R-squared	0.293	0.239	0.422	0.356
Number of Models	333	651	402	930

Standard errors in parentheses clustered by model number

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

The magnitude of the drop was $90.51 for the second-least efficient group (Group 4) and $34.64 for the least efficient group (Group 5) relative to dryers. At the time of the 2007 standard change the average drop in within-model price is significant for the least efficient group once again ($22.66 relative to dryers) and for the middle group (Group 3) with a drop in within-model prices of $26.78 on average relative to dryers. The break in trend is not significant for any group at the time of the 2004 standard. It is significant and negative for all groups at the time of the 2007 standard, but this is also true for dryers, so the trend break relative to dryers is only marginally significant for the second highest efficiency group (Group 2) which began dropping at an additional downward rate of $7.71 per month following the 2007 standard change relative to dryers.

Conclusion

We have shown in this analysis that overall within-model prices of clothes washers have been dropping over time for the most part between 2002 and 2011. Additionally, market shares of purchased appliances have shifted towards greater and greater efficiency. In particular, the clothes washer market share distribution across efficiency levels has been characterized by a bimodal distribution, which has gradually shifted towards greater efficiency, particularly following the implementation of standards.

We have shown that there appears to be an overall downward pressure on prices just around the time of changes to the standard for clothes washers. This downward pressure manifested primarily as an overall drop in within-model prices. For clothes washers in 2004 the average market price (not controlling for any model characteristics) did not change significantly relative to dryers, but the within-model prices of clothes washers dropped significantly relative to dryers at that time, and continued to drop more quickly than dryers in the months following the standard. For clothes washers in 2007 the story was similar, although the drop in within-model prices was not significant relative to dryers.

An important differentiation between the implementation of these two standards is that they both came from the same rulemaking. The law requiring these two standard changes was adopted in 2001 and designed to ratchet up the standards in a two tier process, with one tightening of the standard happening in 2004 and a second in 2007. Prior to the 2004 effective date of the first phase of this process, the clothes washer market had not seen an increase in the minimum standard for 11 years. Once the new standards were adopted in 2001, manufacturers had three years to prepare for the first phase in 2004, but had an additional three years to prepare for the second phase in 2007. Therefore, the fact that these two standards had slightly different impacts on market prices is not surprising, as they reflect perhaps different strategies taken by firms to respond to the standard. For example, the within-model price drop on average was the dominant effect in 2004, while the market average prices didn't change much. This might reflect the fact that firms responded to the standard more by dropping the prices of existing models, not having as much time to introduce new models to the market. On the other hand, in 2007 within-model prices did not drop as much. This might reflect a different strategy by firms to respond to the standard for which they had more time to prepare.

When the models were separated into efficiency quintiles, a story emerged that the downward pressure on prices at the time of the standard seems to have been largely driven by the mid-low efficient level models at the time of both standard changes. Certainly, the price of the two or three lowest efficiency categories did not increase significantly in any regression specification. This is in stark contrast to what would be expected in a perfectly competitive market, wherein a restriction on the supply of low efficiency models should cause an increase in their price, as well as an increase in the price of close substituted (i.e. the next least-efficient models).

Chen et al. (2013) suggest one explanation for the drop in prices is that the industry is experiencing economies of scale. However, this would explain an increasing rate of price drop following the standard, but not an immediate level drop in prices. Additionally, these economies of scale should result in the price drop being concentrated in the most efficient categories. Chen et al. (2013) allude to the possibility that imperfect competition might be another explanation, and as mentioned in the introduction, some researchers have also suggested that perhaps the assumption of perfect competition is not appropriate for appliance markets. The descriptive evidence of the bimodal distribution of sales shares across efficiency levels suggests that this hypothesis of imperfect competition may indeed be worth further exploration. Washer manufacturers must be aware of the heterogeneity of consumer preferences for energy efficiency, but cannot identify which consumers have which preference. Therefore, it suggests that manufacturers, if they have sufficient market power, may have different pricing schemes for different efficiency levels in order to make consumers sort themselves out (self-select) into different efficiency categories to maximize their profit. This type of price discrimination is called second-degree price discrimination and has long been hypothesized as relevant for durables markets (Mussa, et al., 1978; Donnenfeld, et al., 1988; Ronnen, 1991). Empirical work has been done exploring the role of market power on the impact of increasingly stringent CAFE standards (Plourde, et al., 1999; Fischer, 2010), and some recent work has suggested that indeed market power may be a factor in appliance markets (Ashenfelter, et al., 2013).

A model of second-degree price discrimination suggests that producers have an incentive to under-provide efficiency in their least efficiency models in order to charge higher margins for the more efficient models. The implementation of a minimum energy efficiency standard in this setting would eliminate the lowest efficiency models, making it impossible for the producers to maintain the same pricing strategy for higher efficiency models in the short run if they want to extract any surplus from consumers who otherwise would have purchased those now-eliminated least efficient models. They would therefore have to drop the price of models previously overpriced. This is indeed what we see, the price of mid-low quintiles of efficiency dropping in response to increasingly stringent standards. Spurlock (2013) explores the role of market power in this context more rigorously, but these results are suggestive that simplistic assumptions of perfect competition are likely not justifiable for these appliance markets.

References

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

Chen, X., Roberts, M. J., Yang, H.-C., & Dale, L. (2013). Can Standards Increase Consumer Welfare? Evidence from a Change in Clothes Washer. LBNL-6024E.

Donnenfeld, S., & White, L. J. (1988). Product Variety and the Inefficiency of Monopoly. *Economica* , 393-401.

Fischer, C. (2010). Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Light-Duty Vehicles. *Resources of the Future* .

Fischer, C. (2005). On the Importance of the Supply Side in Demand-Side Management. *Journal of Energy Economics* , 165-180.

Fischer, C. (2004). Who Pays for Energy Efficiency Standards? *Resources for the Future*.

Greening, L. A., Sanstad, A. H., & McMahon, J. E. (1997). Effects of Appliance Standards on Product Price and Attributes: An Hedonic Pricing Model. *Journal of Regulatory Economics* , 181-194.

Meyers, S., McMahon, J. E., McNeil, M., & Liu, X. (2003). Impacts of US Federal Energy Efficiency Standards for Residentail Appliances. *Journal of Energy* , 755-767.

Mussa, M., & Rosen, S. (1978). Monopoly and Product Quality. *Journal of Economic Theory* , 301-317.

Plourde, C., & Bardis, V. (1999). Fuel Economy Standards in a Model of Automobile Quality. *Journal of Energy Economics* , 309-319.

Ronnen, U. (1991). Minimum Quality Standards, Fixed Costs, and Competition. *The RAND Journal of Economics* , 490-504.

Spurlock, C. A. (2013). Appliance Efficiency Standards and Price Discrimination. LBNL-6283E.