Ernest Orlando Lawrence Berkeley National Laboratory

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Xiaomei Chen

North Carolina State University,
Department of Agricultural & Resource Economics

Michael J. Roberts

North Carolina State University,
Department of Agricultural & Resource Economics

University of Hawaii at Manoa,
Department of Economics

Hung-Chia Yang and Larry Dale

Energy Analysis & Environmental Impacts Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

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Xiaomei Chen[♣], Michael J. Roberts[♣,♢], Hung-Chia Yang[♠], and Larry Dale[♠]

[♣]North Carolina State University
[♠]Lawrence Berkeley National Laboratory
[♢]University of Hawaii at Manoa

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Abstract

We study prices and sales of individual clothes washer models before, during and after a 2007 standard that banned manufacture (but not sale) of low-efficiency units and increased the threshold for Energy Star certification. While quantities sold of washer models banned from manufacture decreased sharply, prices for banned models increased only modestly. At the same time, sales of higher-efficiency units rose markedly while prices for high-efficiency units declined. On average, washer efficiency increased but prices changed little. A simple welfare analysis indicates that consumer welfare loss from banned washers was far outweighed by gains from lower-priced high-efficiency units. While a full cost-benefit analysis is not feasible with the available data, we estimate a lower-bound gain in consumer surplus equal to 6-16 percent of total sales. This result may accord with earlier theoretical research that shows quality standards can increase welfare in monopolistically competitive industries that possess increasing returns to scale (Ronnen, 1991). Thus, if energy efficiency is a close proxy for quality, energy efficiency standards may increase competition, market efficiency and welfare.

1 Introduction

Minimum quality standards are a prevalent feature of regulation, particularly with regard to energy efficiency and safety of buildings, cars, and appliances. In the conventional model of a competitive economy with perfect information, it is not clear how such standards might improve social welfare. Rather, minimum quality standards are normally justified using models of asymmetric information (Leland, 1979), imperfect competition (Ronnen, 1991) or perception bias (Allcott, 2011). Government's regulatory analyses typically justify standards by explicitly evaluating the costs and benefits of specific product attributes that affect efficiency and safety. There are at least two problems with this approach: it generally requires strong and often unverifiable assumptions about intangible costs and preferences and it cannot account for the influence of standards on market and industry structure.

In this study we take a new and simple approach to empirically evaluate a change in standards. We exploit a 2007 policy change in energy efficiency standards for clothes washers to obtain direct evidence on the consumer welfare impact of the more stringent energy efficiency standard. This policy change increased both the minimum threshold of energy efficiency and the threshold for Energy Star certification. The minimum threshold increased from a Modified Energy Factor (MEF) of 1.04 to 1.26; energy star certification increased from 1.42 to 1.72. (MEF measures the ratio of the capacity of the washer to the energy used in one cycle.) We exploit this policy change as an exogenous intervention in the washer market and examine how prices and quantities sold of different washer types changed with the policy. This analysis allows for partial identification of consumer welfare impacts, including a lower bound on the net change in consumer surplus. The results indicate a positive change in consumer welfare and indicate a pattern of response that aligns with Ronnen's model of imperfect competition and economies of scale (Ronnen, 1991).

2 Consumer Welfare Analysis of a Change in Standards

The 2007 change in clothes washer standards could have had a wide range of economic impacts on consumers. To evaluate these effects, it helps to treat the washer market as a mix of different types of washer, which vary in quality, functions, size, efficiency levels, and manufacturer reputation. The policy change effectively phased out one portion of the washers in the market, by banning the manufacture of the least efficient washer units and changed Energy Star labeling criteria for another portion of the washer market. This change in policy only affected the manufacture of washer units, not unit sales, so the supply of unqualified units was not completely eliminated from the market when the standards were first enacted.

Under standard assumptions of perfect competition and decreasing returns to scale in washer unit production, the policy changes would have two main effects: (1) supply of low-efficiency washers would decrease sharply, and the inward-shifting supply curve would result in a decrease in quantity and an increase in price for less efficient washers (Figure 1); (2) demand for high-efficiency washers would increase significantly, and the outward-shifting demand curve would lead to an increase in both quantity and price for more efficient washers (Figure 2, Panel A). If, however, washer manufacturers have pricing power, or there are increasing returns to scale in washer production (cost per unit declines with volume), or both, prices for higher efficiency units might fall (Figure 2, Panel B). In this case, the downward-sloping supply curve portrays increasing returns to scale in clothes washer production.

Ideally, an estimate of the policy's net effect on consumer welfare would account for demand and competition across all types of washers. Although the ban of low-efficiency washers would generally increase demand for washers not banned, depending on the shape of aggregate preferences, demand for any particular washer may increase or decrease. Further, if there is monopolistic competition, the ban of inefficient washers may cause the market for efficient washers to become more competitive, which could make type-specific demands more elastic. The change in Energy Star threshold could influence consumers' information about relative washer quality, which could further shift individual washer demands.

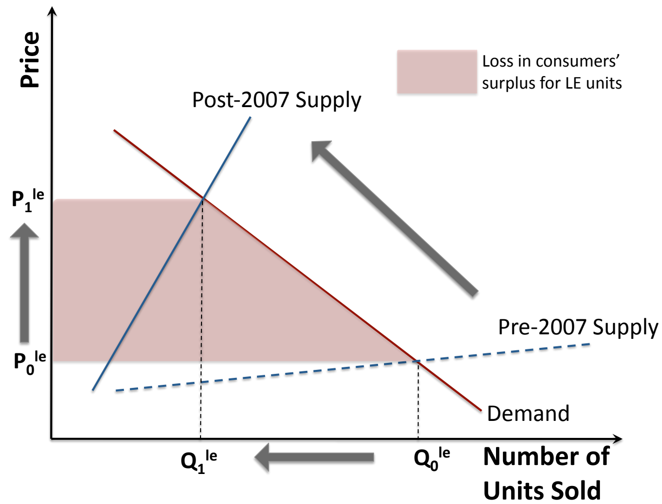
To account for these many different kinds of possible demand shifts without making strong assumptions about preferences or market structure, we use a rich data set on quantities and prices of every individual model sold, and attempt to estimate the causal effect of the policy change on each one. Although we do not observe costs or washerspecific demand elasticities, changes in prices and quantities can, by themselves, reveal a minimum change in consumers' surplus, regardless of the underlying market structure, as we explain below.

New standards are usually published a couple of years in advance of the effective date; therefore, washer manufacturers may have adjusted their production plan and pricing strategy well before the standards actually take effect. Producers and consumers may rush to make or buy washers about to be banned from manufacture. The transition period could be long because washers are durable goods and washers manufactured prior to the ban may still be sold.

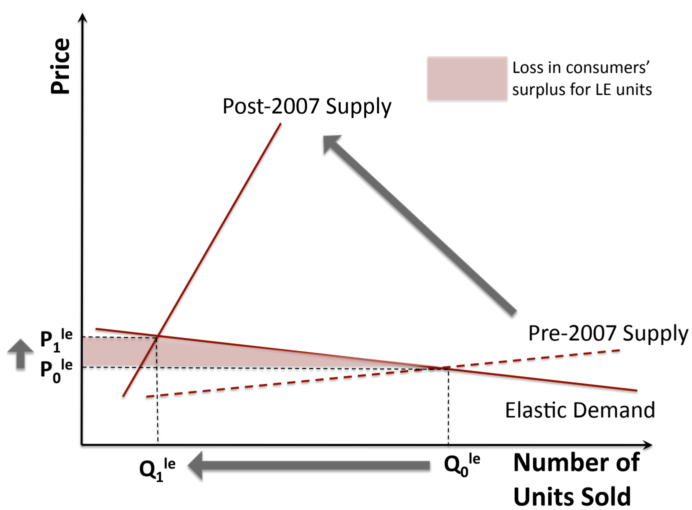
Putting aside issues related to market transition, the net welfare change resulting from a change in standards cannot be fully identified from ex-ante and ex-post prices and quantities of each washer. One key problem is that we cannot identify the slope of demand for units not banned from manufacture. Taking estimated changes in price

Figure 1: The standard change reduces supply of low-efficiency units.

Panel A

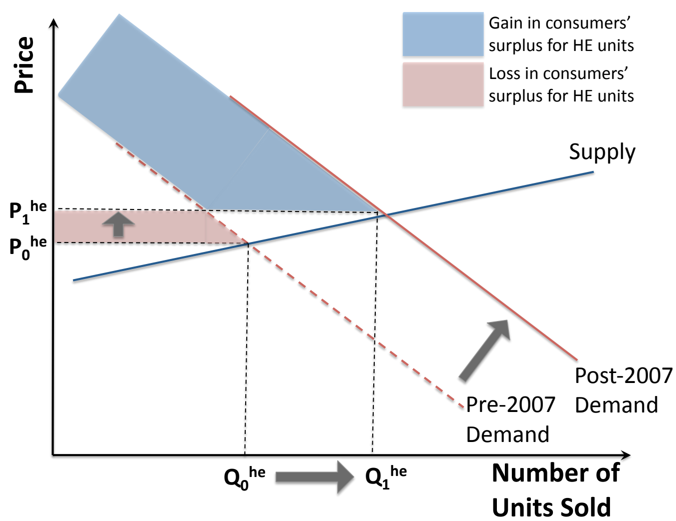


Panel B

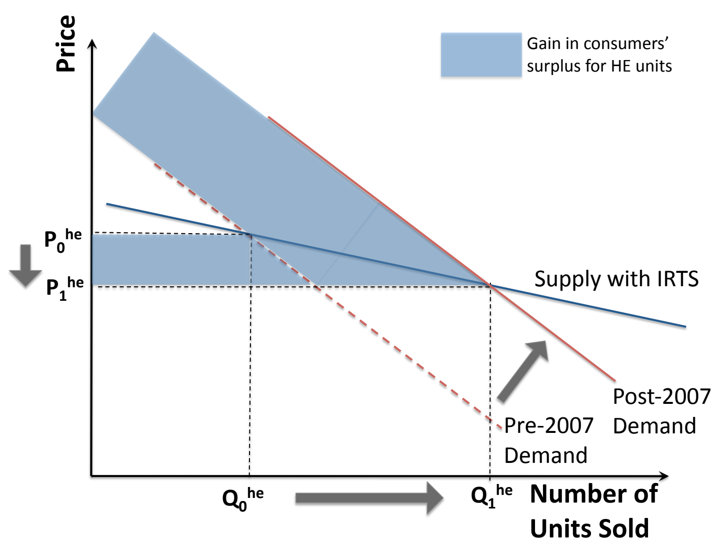


The top panel shows a hypothetical market with supply and demand for low-efficiency washer units. The policy change causes supply curve to shift inward, causing a loss in consumer surplus equal to the shaded area. In the bottom panel, demand for low-efficiency units is flatter and the consumer surplus loss is greater. But we cannot identify the supply curve from policy's effects on price and quantity.

Figure 2: The standard change shifts out demand for high-efficiency units.
Panel A



Panel B



The top panel shows a hypothetical market with supply and demand for high-efficiency units. The policy change causes prices of low-efficiency units to increase, which causes demand for high-efficiency units to shift out, which increases quantity and price and consumer and producer surpluses. In the bottom panel, supply is downward sloping due to increasing returns to scale, and price falls rather than increasing. We cannot identify the size of surplus benefits because the slope of the demand curve cannot be identified from the policy's effects on price and quantity.

and quantity as given, we are able to derive the loss in consumer surplus in the banned low-efficiency market, shown as the shaded area of Figure 1. This value is identifiable because changes in price and quantity occur along the demand curve, and the slope of the demand curve for low-efficiency washers is revealed by the observed changes in price and quantity. If the price increase is large, it implies the demand curve is relatively steep (more inelastic) and the loss in consumer surplus is expected to be large as well (Figure 1, Panel A). On the other hand, if the price increase is small, it implies the demand curve is relatively flat (more elastic), and the loss in consumer surplus is small too (Figure 1, Panel B).

What we cannot estimate is the gain in consumer surplus due to the policy induced outward shift in demand for high-efficiency washers (Figure 2). Here, changes in price and quantity resulting from a shift in demand occur along the supply curve so the slope of demand is not identifiable. As a result, the most we could measure is how marginal cost changes with quantity sold. The problem is we cannot disentangle the shift in demand from movement along the demand curve, both of which are needed to measure the change in consumer surplus.

Nevertheless, we can see that the smaller the price increase, the more likely there will be a net gain in consumer surplus in the high-efficiency market, as shown in Panel A of Figure 2. In this case, the blue trapezoid is likely to be greater than the red trapezoid. If prices actually decrease due to economies of scale (Figure 2; Panel B), there are ambiguous consumer gains in the high-efficiency market. We cannot identify how much they gain because we cannot discern how much of the quantity and price changes are due to movement along the demand curve verses a shift in demand. Still we can obtain a lower bound estimate for the gain using the area of the lower blue trapezoid traced out by points $(0, P_0^{he}), (0, P_1^{he}), (Q_1^{he}, P_1^{he})$ and (Q_0^{he}, P_0^{he}). This calculation assumes the shift in demand makes up an arbitrarily small share of observed changes in price and quantity while movement along the demand curve makes up an arbitrarily large share of observed changes. This equals the lower bound of the total consumer surplus change, because it excludes the positive welfare gain from the upper blue trapezoid area in Panel B of Figure 2, which is not identifiable since we cannot identify the slope of the demand curve for higher efficiency washers.

We can generalize the lower bound estimate of total change in consumer surplus to account for every washer model sold in the market, as following:

$$\text{Minimum Change in Consumers' Surplus} = \sum_i \frac{1}{2} \left(p_0^i - p_1^i\right) \left(q_0^i + q_1^i\right) \tag{1}$$

where p_0^i and p_1^i are prices for washer model i before and after the policy change, and q_0^i and q_1^i are their respective quantities sold.

The equation gives the sum of trapezoid areas outlined by prices and quantities from the pre- and post-standard periods for each washer model. For models with an increase in price after the standard, the corresponding trapezoid area will be assigned with a negative value, implying a loss in consumer surplus, as illustrated by the red-shaded area in Figure 1. For models with a decrease in price after the standard, the associated trapezoid area will be assigned a positive value, which is akin to the lower blue-shaded trapezoid area in Panel B of Figure 2. Given model-specific estimates of changes in prices and quantities, we can therefore construct a lower-bound estimate of the net impact of total consumer surplus due to efficiency standards.

Note that inference about the lower bound of consumer surplus change does not depend on industry structure. Although we have drawn the figure as if the washer market is a perfectly competitive, possibly one with increasing returns to scale, the welfare analysis only concerns consumers' surplus and the structure of demand. It need not be the case that observed price equals marginal cost before or after the policy change. Shrinking producer margins from increased competition may also explain falling prices and increasing quantities.

Another way to view the lower-bound approximation is to draw on ideas akin to Le Chatelier's principle (Samuelson 1947). In banning a portion of the washer market, a worst-case scenario with respect to consumers is to assume extremely limited substitution between washer types. In the extreme case, demand across all submarkets would be fixed: prices and availability of different washers would not shift demands of any other washers. We could then evaluate the change in consumer surplus assuming all changes in prices and quantities were along demand curves and none of the changes came from shifts in demand. If, however, consumers' demands are responsive to prices of substitute washers, then consequent shifts in demand must improve consumer welfare relative to the case where we assume no substitutability. This is precisely the calculation used to calculate the minimum change in consumers' surplus.

3 Assessing the Value of Washer Attributes

Some concern has been raised regarding the impact of policy changes on the quality and characteristics of washing machines. Although some attributes of washerssuch as energy efficiency, capacity, soil sensors and spin speedarguably 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. Quality, after all, depends on the tastes and preferences of individual buyers. Changes perceived as improvements to some consumers may be seen as detriments to others. The impact of standards on consumer surplus should embody the economic value of these quality changes, which may affect the demand of high-efficiency washers. For example, if new washer designs made available due to the 2007 policy change were particularly undesirable to the majority of consumers, then the relative scarcity of banned washers that were still available after 2007 should have led to a significant increase in old washer prices and this would have resulted in greater consumer loss, as shown in Panel A of Figure 1. On the other hand, if the new washers were close substitutes to the banned washers in terms of washer attributes and functionalities, demand for low-efficiency washers would become relatively elastic, as shown in Panel B of Figure 1.

One might be able to obtain direct engineering measurements of changes in washer quality. Engineering measurements typically apply standardized tests to evaluate washer performance. Engineers, for example, could test whether washers manufactured before the ban tended to last longer without malfunction, test the length of wash, and so on. Consumer surveys could also be used to evaluate consumer preferences towards different washers. Alternatively, values of attributes might be estimated using a hedonic approach that relates attributes of washers to their prices, but this approach must assume preferences are homogeneous. However, we were not able to acquire detailed engineering data or comprehensive consumer reports associated with washer models; therefore, these approaches are not included in this study.

Instead, we use regression models with fixed-effects to estimate washer-specific changes in quantities and prices. Revealed preferences give direct lower-bound measures of consumer surplus without imposing strong assumptions about preferences, transaction costs, or discount rates. This approach does not require underlying assumptions about homogeneous preferences, like the hedonic regression approach. Similarly, it does not require econometric assumptions that are as strong as cross-sectional hedonic regression model approach. However, this approach does assume that consumers generally make rational decisions when purchasing clothes washers so that policy-induced changes in prices and quantities reflect individual values. In the following sections, we detail the data source used in this clothes washer study and the application of the fixed-effect model.

A possible concern with our approach is that many other factors changed concurrently with the 2007 policy change that may have affected washer prices and units sold, including shifts in demand from non-policy factors and technological changes driven by non-policy factors. These factors include changes in energy prices, the collapse of the housing market, the recession that began at the end of 2007, and the subsequent financial crisis and prolonged downturn in the aggregate economy. We attempt to control for these factors as well as possible using standard panel regression techniques and time trends, but they may nevertheless confound the estimated effects of the 2007 policy change on prices and quantities sold. At worst we believe our estimates of changes in consumer surplus are biased too low.

4 Data and its Limitations

We obtained point-of-sale (POS) data on total sales of washers purchased in the United States from NPD Group, with measures for units sold and average price broken down by washer brand and model. NPD collects monthly POS data from major household appliance retailers in the U.S. market, including units sold and sales revenue of each model. The data include a limited set of attributes for each model, including washer size, color and type. For a large majority of models, this information was was merged with a data set with a Federal Trade Commission (FTC) assessment of energy efficiency measured as kilowatt-hours per year (kWh/y) for standard usage. The FTC measure of energy efficiency cannot be converted to the U.S. Department of Energy's (DOE's) MEF measure, because the FTC measurement does not fully account for the energy used for removing the remaining moisture in the clothes, which reduces subsequent drying time.

If precise MEF data were available and matched to each washer, one approach might be to consider separately four categories of washers: (1) those that met the minimum standard before and after the 2007 change (2) those that met the minimum standard before 2007 but not after; (3) those that met the Energy Star threshold before and after 2007; and (4) units that met the Energy Star threshold before 2007 but not after the policy change. Because we do not have MEF data, we proxy for washers that may have been closer and further from the 2007 minimum and Energy Star standards using the FTC measure of efficiency (kWh/y). We do not have this measure for all units, but we do have it for a significant majority of models in our data. Specifically, we divide units into Energy Star and non-Energy Star, and we further divide each of these subsamples by the median FTC measure of efficiency (kWh/y). This gives us four categories of washers including those that consume less than and more than the median energy use among the Energy Star qualified units and those that consume more than and less than the median energy used among the non-Energy Star qualified units.

We also consider a limited sample of washers that includes only models that were sold both before and after the 2007 policy change. The limited sample facilitates an "apples to apples comparison of washer prices before and after the 2007 policy changes. Summary statistics for these data, broken down by each sub-group and category, are reported in are reported in table 1 and table 2.

Table 1: Summary Statistics of the Full Sample

	Energy Star				non Energy Star			
	High Efficiency		Low Efficiency		High Efficiency		Low Efficiency	
	pre-2007	post-2007	pre-2007	post-2007	pre-2007	post-2007	pre-2007	post-2007
Units Sold/month	16,993	95,301	39,941	44,649	14,291	70,580	46,999	14,763
Average Prices (Current $)	992.91	816.91	804.08	758.86	290.68	419.92	390.64	436.81
Std. Deviation of Price	183.32	265.89	315.19	245.65	82.37	152.73	149.23	117.68
Front Loading (%)	98.9	97.3	47.5	32.1	1.1	4.8	0.0	0.0
Top Loading (%)	1.1	2.7	52.5	67.9	98.9	95.2	100.0	100.0
Average FTC (kwh/year)	178.82	160.51	342.80	269.26	413.54	358.43	731.75	511.47
Std. Deviation of FTC	10.64	19.93	150.50	68.42	42.84	76.44	151.21	96.83
Average # of Cycles	7.89	9.52	12.56	12.09	7.36	9.20	8.70	13.73
Std. Deviation of # of Cycles	2.25	2.71	4.06	2.75	3.30	3.88	3.40	5.10
Average RPMs	1,066	1,145	949	1,091	678	874	714	649
Std. Deviation of RPMs	128	125	197	185	131	294	204	116
Side by Side (%)	22.3	14.6	55.4	68.8	89.1	90.2	89.9	95.3
Portable Side by Side (%)	0.0	0.0	0.0	0.0	9.8	0.6	0.7	0.2
Stackable (%)	75.9	84.7	40.7	30.7	1.1	2.3	0.0	0.0
Prestacked (%)	0.0	0.2	3.6	0.4	0.0	6.8	9.5	4.5
Portable Stackable (%)	0.6	0.3	0.0	0.0	0.0	0.1	0.0	0.0
Washer/Dryer Combo (%)	0.7	0.0	0.3	0.1	0.0	0.0	0.0	0.0
Portable Washer/Dryer Combo (%)	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Not Specified (%)	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Load Sensor (%)	79.2	53.7	30.8	27.2	0.0	6.3	0.2	0.1
Soil Sensor (%)	6.5	2.2	25.8	17.2	0.6	6.1	11.7	17.1
Soil and Load Sensor (%)	10.7	32.1	3.4	17.1	1.1	0.0	0.0	0.0
No Sensor (%)	1.1	8.9	30.7	37.5	96.7	84.2	76.7	82.0
Not Specified (%)	2.5	3.1	9.3	1.1	1.7	3.4	11.3	0.8
Average Capacity (Cu. Ft.)	3.59	3.88	3.52	4.06	2.95	3.30	3.29	3.48
Std. Deviation of Capacity	0.27	0.37	0.29	0.36	0.25	0.32	0.39	0.32
Electronic Control (%)	96.59	98.27	58.26	80.28	1.28	4.37	1.96	0.21
Mechanic Control (%)	3.16	1.73	41.62	19.67	98.72	95.57	98.04	99.79
Not Specified (%)	0.25	0.00	0.12	0.05	0.00	0.07	0.00	0.00

Notes: Full sample includes all data with and FTC energy efficiency rating. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population. Monthly data from 2004 - 2009 are used in this analysis, with total 36 months before 2007 and 35 after 2007 due to missing data in December 2008. All averages and standard deviations are weighted by total units sold during that period. Characteristics such as # of Cycles, RPMs, and Capacity are recorded as ranges; middle point of the range is used when calculating the average. For example: 1099.5 RPMs is used for those washers with RPMs in the range 1000-1199. For the ranges with one boundary, the boundary is used in the calculation. For example: 2.5 cubic feet is used for those with less than 2.5 cubic feet and 4.5 is used for those with 4.5+ cubic feet. Data with "Not Specified" characteristics are treated as missing data and not included in the calculation of the characteristic average.

Table 2: Summary Statistics of the Limited Sample

	Energy Star				non Energy Star			
	High Efficiency		Low Efficiency		High Efficiency		Low Efficiency	
	pre-2007	post-2007	pre-2007	post-2007	pre-2007	post-2007	pre-2007	post-2007
Units Sold/month	21,657	24,376	31,064	13,630	17,748	19,339	32,801	2,462
Average Prices (Current $)	992.22	772.33	782.85	814.45	341.13	372.47	391.23	426.83
Std. Deviation of Price	214.70	258.26	303.48	181.75	131.09	113.98	159.42	183.92
Front Loading (%)	97.6	90.3	40.2	23.2	0.1	0.0	0.0	0.0
Top Loading (%)	2.4	9.7	59.8	76.8	99.9	100.0	100.0	100.0
Average FTC (kwh/year)	193.80	176.12	343.21	328.05	446.84	402.98	715.61	735.42
Std. Deviation of FTC	25.10	25.53	121.12	74.50	65.94	56.06	131.72	112.76
Average # of Cycles	9.33	8.70	11.49	11.28	8.50	7.18	9.31	9.84
Std. Deviation of # of Cycles	2.83	2.71	3.33	2.40	3.71	2.75	3.65	4.13
Average RPMs	1,093.56	1,117.31	910.89	1,039.85	638.22	625.54	711.55	725.90
Std. Deviation of RPMs	119.30	129.45	186.77	144.20	105.50	29.24	211.28	224.06
Side by Side (%)	12.1	37.4	62.8	78.3	92.5	97.4	87.5	78.4
Portable Side by Side (%)	0.0	0.0	0.0	0.0	5.4	1.1	0.2	0.5
Stackable (%)	86.8	60.7	32.8	20.2	0.0	0.0	0.0	0.0
Prestacked (%)	0.4	0.1	4.0	1.1	2.1	1.5	12.3	21.1
Portable Stackable (%)	0.5	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Washer/Dryer Combo (%)	0.0	0.0	0.4	0.3	0.0	0.0	0.0	0.0
Portable Washer/Dryer Combo (%)	0.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Load Sensor (%)	60.4	61.8	35.9	67.3	0.7	0.1	0.0	0.0
Soil Sensor (%)	15.5	4.3	25.2	7.9	20.5	17.2	2.6	4.9
Soil and Load Sensor (%)	10.8	19.4	1.8	22.5	0.0	0.0	0.0	0.0
No Sensor (%)	11.6	13.6	28.7	1.5	76.3	82.0	90.2	91.7
Not Specified (%)B	1.7	0.8	8.4	0.8	2.5	0.7	7.2	3.4
Average Capacity (Cu. Ft.)	3.61	3.55	3.51	4.02	3.02	3.18	3.37	3.45
Std. Deviation of Capacity	0.24	0.36	0.30	0.45	0.27	0.28	0.41	0.49
Electronic Control (%)	89.2	92.0	60.0	91.3	0.9	0.3	0.2	0.5
Mechanic Control (%)	10.8	8.0	40.0	8.7	99.1	99.7	99.8	99.5

Notes: Limited sample is a subset of the full sample that includes all washer models observed in the data at least once before and after the 2007 policy change data. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular (limited) sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population. Monthly data from 2004 - 2009 are used in this analysis, with total 36 months before 2007 and 35 after 2007 due to missing data in December 2008. All averages and standard deviations are weighted by total units sold during that period. Characteristics such as # of Cycles, RPMs, and Capacity are recorded as ranges; middle point of the range is used when calculating the average. For example: 1099.5 RPMs is used for those washers with RPMs in the range 1000-1199. For the ranges with one boundary, the boundary is used in the calculation. For example: 2.5 cubic feet is used for those with less than 2.5 cubic feet and 4.5 is used for those with 4.5+ cubic feet. Data with "Not Specified" characteristics are treated as missing data and not included in the calculation of the characteristic average.

5 Price and Quantity Changes Over Time

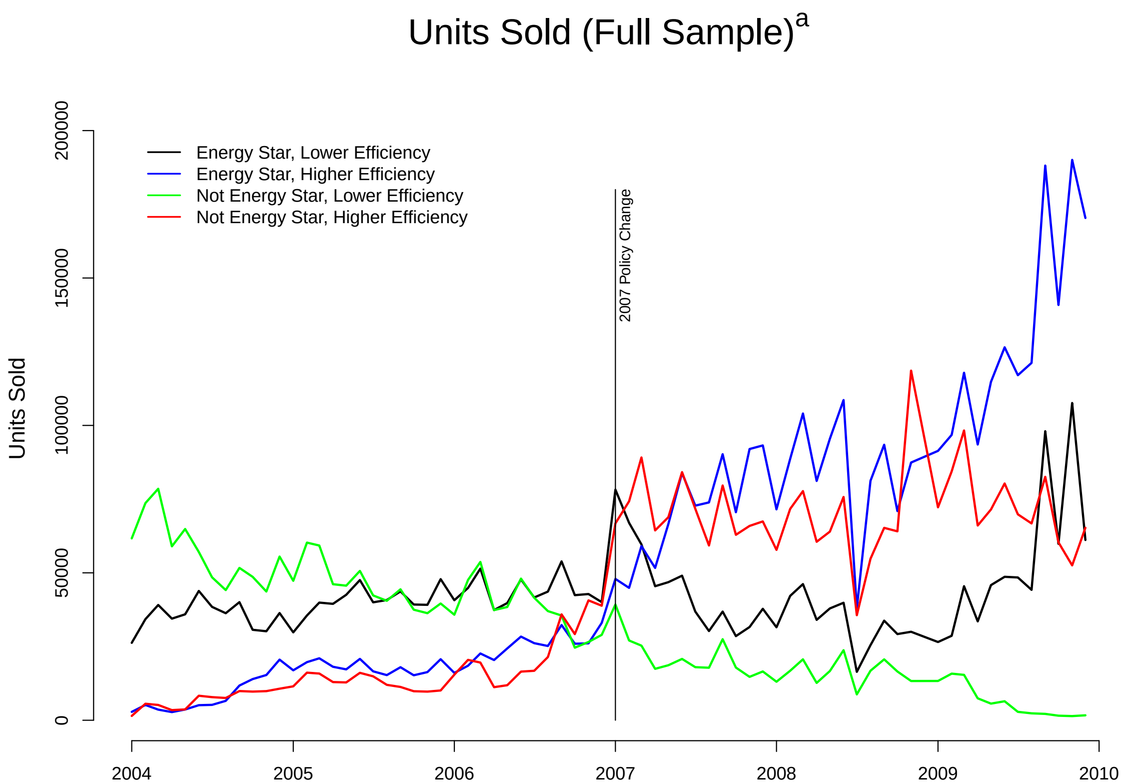
The data described above are plotted in Figure 3 through Figure 8. The figures show prices, units sold, and shares of units sold for each of the four categories of washer, for both the full sample and the limited sample that only includes units sold both before and after the 2007 policy change. All prices are adjusted for inflation using the Consumer Price Index and reported in 2010 dollars. The average price taken across all units sold in the sample (individual washers weighted by quantity sold) are also shown. The data appear to show a slight discontinuity in quantities and prices around the time of the policy change. Prices decline for high-efficiency units and prices increase slightly for low-efficiency units. Note that all prices are in current dollars. The upward trend in the market share of more efficient washers, with a strong shift toward Energy Star units, started before the 2007 policy change, and the trend continued well after the amended standards. The longer-run trends are obviously difficult to disentangle from other factors influencing technological advance and demand. Despite the marked shift in purchasing behavior toward more-efficient units, nominal average prices show little if any trend upward, even in the full sample. As the more-efficient units appear to be falling in price faster than less-efficient units, the concurrent trends in prices and quantities provide some evidence of scale economies.

6 Regression Models

Fixed-effect models are used to explore the relationship between dependent variables and independent variables that are both time-variant and have within-individual variation. Here we attempt to discern model-specific effects of the policy on price and quantity of units sold using a fixed-effect, regression-discontinuity framework. This regression includes fixed effects for each washer model and smooth, or spline, functions of time to account for other factors changing around the time of the policy. Modeling fixed effects removes all model-specific features of washers so that price effects cannot be attributed to changes in quality or characteristics over time. With this type of analysis, we attempt to explain how individual model prices and quantities change over time, and whether these changes were unusually sharp around the 2007 policy change.

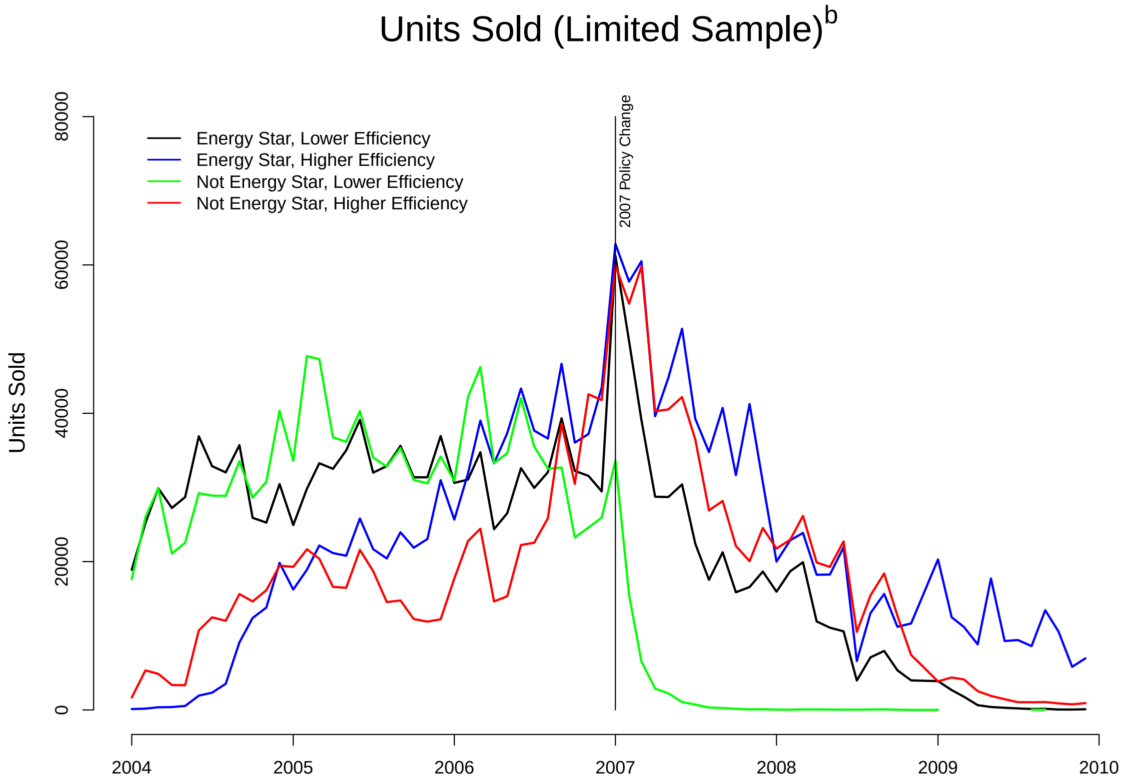
The effect of the policy itself is estimated with a dummy variable to capture effects around the time of the policy change under the maintained assumption that the change itself is exogenous conditional on a flexible time-trend control. We also included an interaction term between the 2007 policy dummy variable and the energy efficiency level, measured in kWh per year, because this allows us to control for unobserved time-varying effects related to energy efficiency and gain insights into the variations

Figure 3:



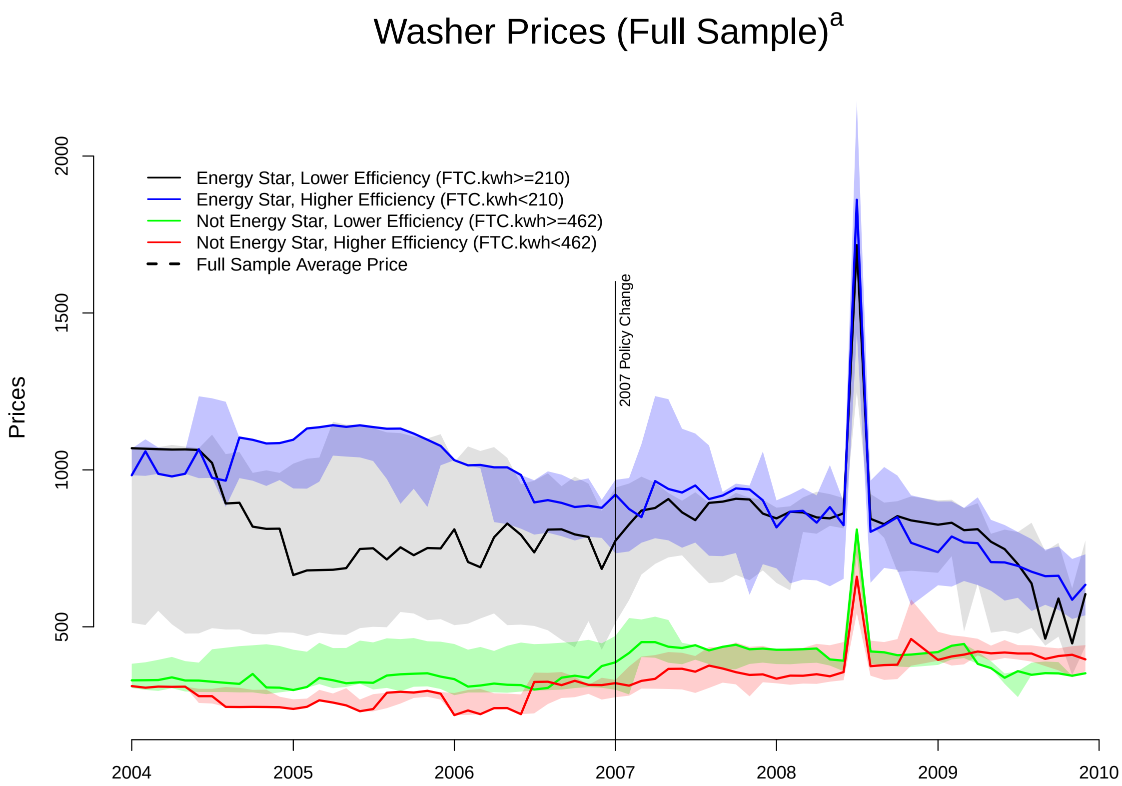
[a]Full sample includes all data with and FTC energy efficiency rating. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population.

Figure 4:



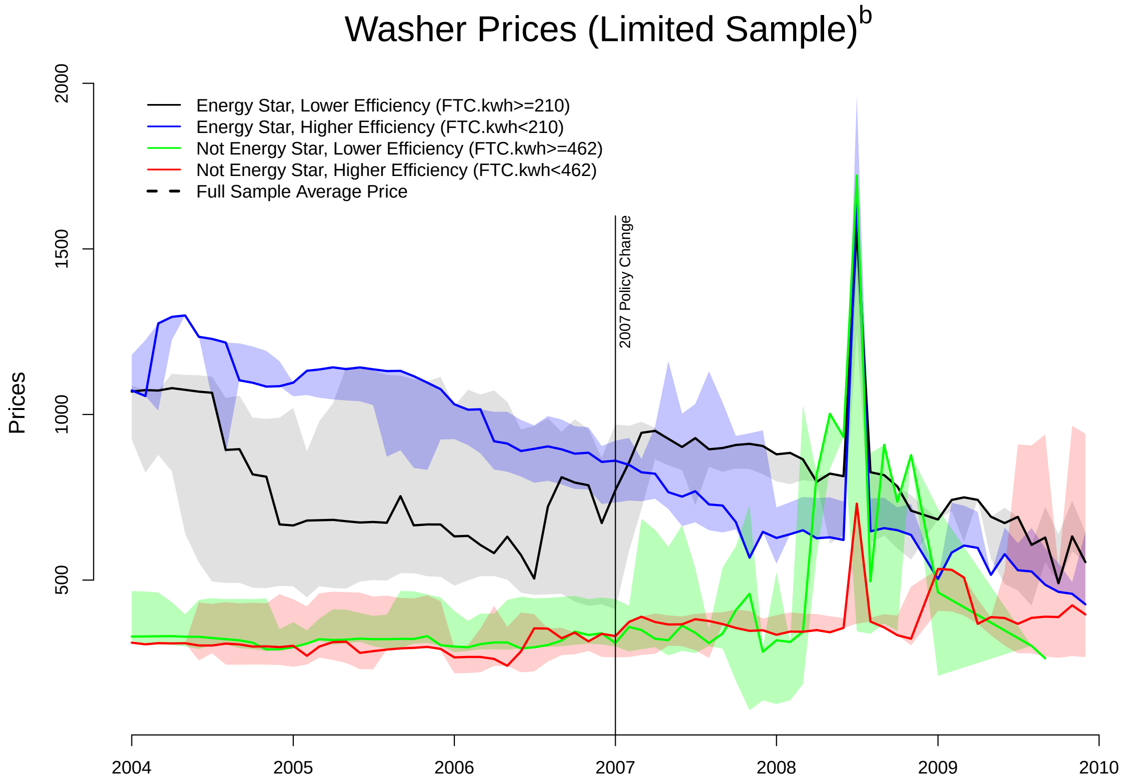
[b]Limited sample is a subset of the full sample that includes all washer models observed in the data at least once before and once after the 2007 policy change data. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular (limited) sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population.

Figure 5:



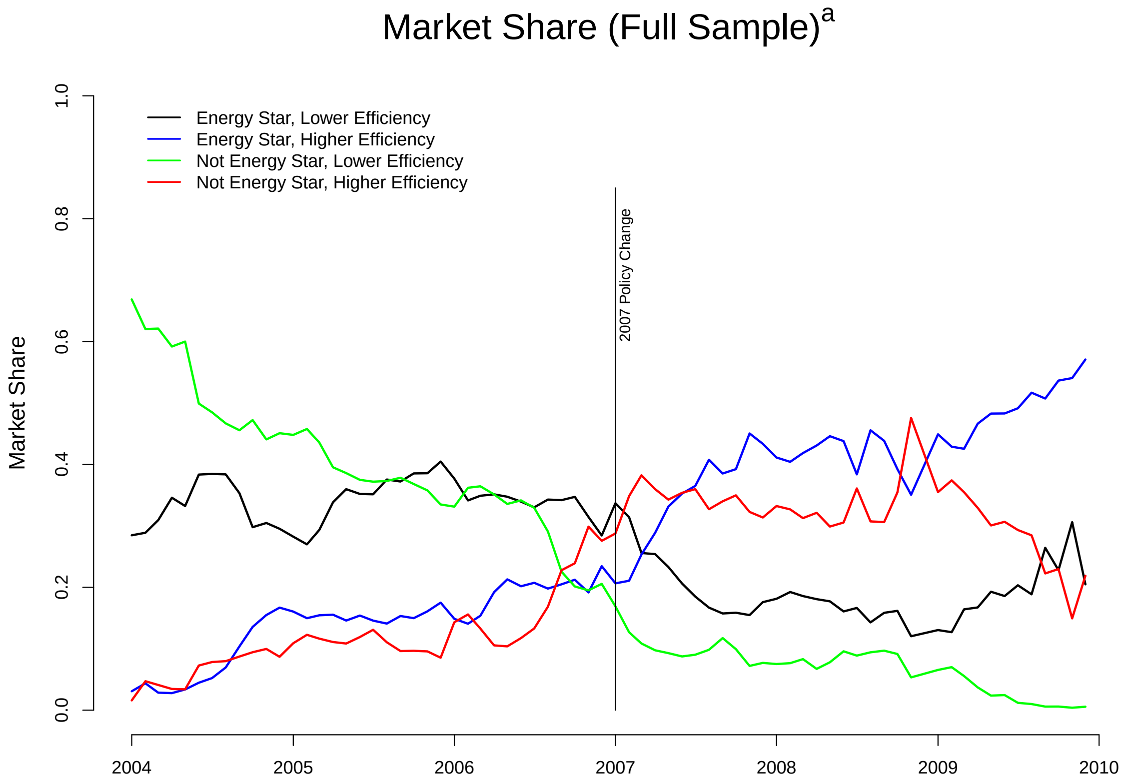
[a]Full sample includes all data with and FTC energy efficiency rating. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population. The lines for each category of washer indicate the value for the median washer sold in that category, and the band around the line marks the first and third quartiles. The thick dashed line is the average price across all models, with models weighted by number of units sold.

Figure 6:



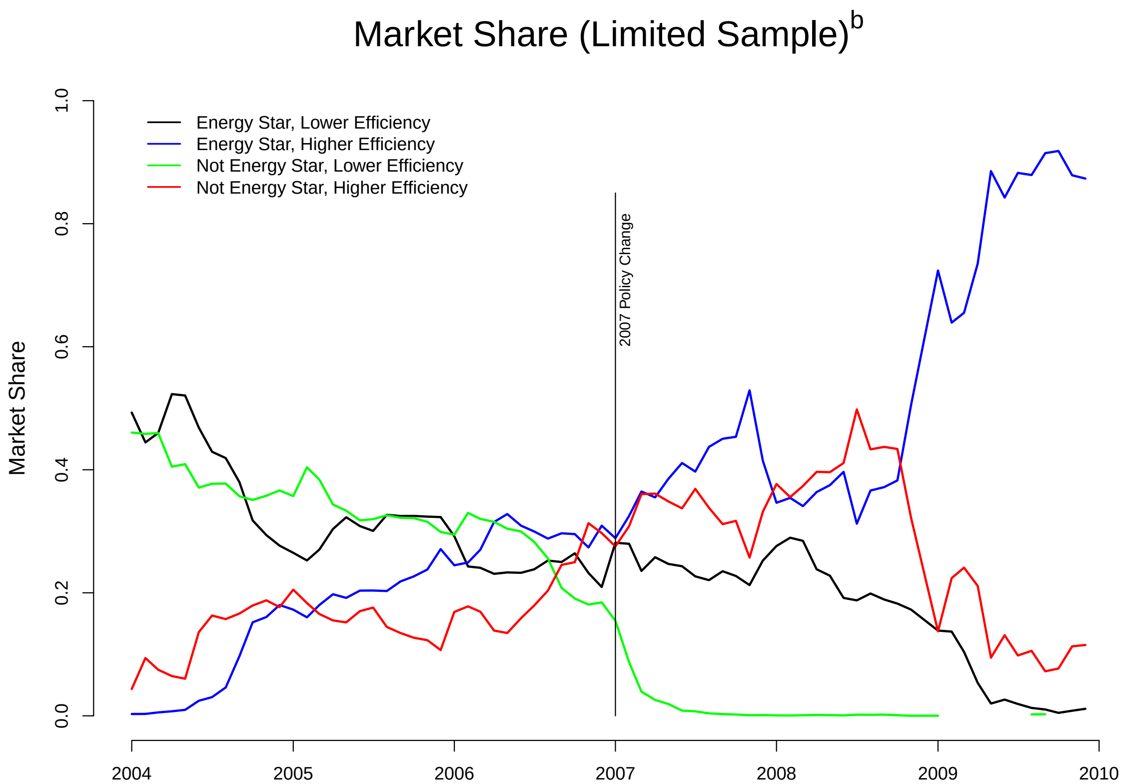
[b]Limited sample is a subset of the full sample that includes all washer models observed in the data at least once before and after the 2007 policy change data. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular (limited) sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population. The lines for each category of washer indicate the value for the median washer sold in that category, and the band around the line marks the first and third quartiles. The thick dashed line is the average price across all models, with models weighted by number of units sold.

Figure 7:



[a]Full sample includes all data with and FTC energy efficiency rating. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population.

Figure 8:



[b]Limited sample is a subset of the full sample that includes all washer models observed in the data at least once before and after the 2007 policy change data. High and low efficiency values are selected according to the median value of the FTC energy rating taken across model numbers in this particular (limited) sample. Note that the data include a varying number of retailers over time and the sample of retailers may not be representative of the population.

in price effects by efficiency level. It is important to note that the regression frameworkakin to a regression discontinuityis not especially well suited to this particular policy change due to the factors described in the opening section: (a) the change was anticipated in advance and likely influenced behavior long before and long after the event of the change, and (b) many other factors were likely influencing the appliance industry around the time of the policy change. As we detail in the discussion below, these factors suggest that our estimated minimum change in consumers' surplus may be biased too low. A spline function with four knots was added to the model to impose continuity restrictions at the joint points and force the regression to have a smoother transition when an exogenous shock takes place.

The baseline regression models are specified as follows:

$$q_{it} = \alpha_i + f(t) + \beta_q d2007 + \gamma_q (d2007 \times kWh/y_i) + \epsilon_{it} \tag{2}$$

$$p_{it} = \alpha_i + f(t) + \beta_p d2007_t + \gamma_p (d2007_t \times kWh/y_i) + \epsilon_{it} \tag{3}$$

where $d2007_t$ is a dummy variable indicating the policy change in 2007, $f(t)$ is a spline function of time, and kWh_i is energy efficiency measured in kilowatt hours per year for each washer model.

We also estimated models with more robust controls for time, achieved by interacting smooth functions of time with each of the four categories of washers described in section 4, denoted as $f_c(t)$. The models with trend interactions are:

$$q_{it} = \alpha_i + f_c(t) + \beta_q d2007_t + \gamma_q (d2007_t \times kWh/y_i) + \epsilon_{it} \tag{4}$$

$$p_{it} = \alpha_i + f_c(t) + \beta_p d2007_t + \gamma_p (d2007_t \times kWh/y_i) + \epsilon_{it} \tag{5}$$

All regressions are estimated using both the full sample of washers and the limited sample of washers with transactions observed both before and after the 2007 policy change. The smooth functions of time are estimated using a natural cubic spline, each with four knots and three degrees of freedom.

Results from these regressions are reported in table 3. The results suggest the policy change caused prices for most washers to fall and quantities to increase. The positive sign of the coefficient for the interaction term in the price model implies that the price of high-efficiency washers would decrease faster compared to less-efficient washers, and the effect reverses for low-efficiency washers. The sign reverses for the most inefficient units. Analogously, the negative sign of the coefficient for the interaction term in the quantity model implies that the quantity sold of high-efficiency washers increased faster compared to low-efficiency washers, and the effect reverses for low-efficiency washers. The most inefficient units with positive price effects and negative quantity effects were likely banned as a result of the policy change, as these units vanish from the data set, or nearly so, in later months.

Table 3: Summary of Regressions

	Price Effect of Policy			Quantity Effect of Policy		
	β	γ	Adj. R^2	β	γ	Adj. R^2
	Estimate/(t-statistic)					
Basic—Full Sample	-198.24	0.27	0.86	580.26	-1.00	0.57
	(-18.20)	(13.57)		(5.64)	(-5.36)	
Robust—Full Sample	-86.56	0.06	0.87	694.18	-1.36	0.57
	(-6.90)	(2.38)		(5.64)	(-5.24)	
Basic—Limited Sample	-149.13	0.26	0.88	823.12	-1.20	0.54
	(-14.57)	(15.04)		(7.79)	(-6.73)	
Robust—Limited Sample	-48.53	0.02	0.90	600.09	-0.64	0.54
	(-3.85)	(0.785)		(4.37)	(-2.34)	

Notes: All regression models include fixed effects for each model of washing machine. *Basic* models include a natural spline of time (on a monthly scale) with four knots. *Robust* models include a separate natural spline of time for each of the four classes of washer as classified in the data section and plotted in the above figures. The β coefficient is for the dummy variable indicating the post-2007 time period. The γ coefficient is the effect on the interaction of the year-2000 dummy variable and the unit's FTC energy-efficiency rating, measured in kWh of energy use per year.

7 Minimum Change in Consumers' Surplus

In section 2 above we described an estimate for the minimum loss in consumers' surplus as:

$$\text{Minimum Change in Consumers' Surplus} = \sum_i \frac{1}{2}\left(p_0^i - p_1^i\right)\left(q_0^i + q_1^i\right) \tag{1}$$

To derive this value from the estimated regressions, we define baseline quantities and prices and then infer the policy-induced difference in quantities and prices from the data and regression coefficients. Although the change in prices and quantities is clearly defined by the regression coefficients, there are several ways to select baseline prices and quantities, given the fact that some washer models entered and exited the database at least in part due to the policy. We therefore consider three baseline prices and quantities using: (a) average value shortly before and after the 2007 policy change;

(b) average ex-ante prices and quantities; and (c) average ex-post prices and quantities. We added the estimated difference derived from the regression to find ex-post prices and quantities and subtracted the estimated difference derived from the regression to find ex-ante prices and quantities.

Specfically, we define:

$$\Delta p^i = \hat{\beta}_p + \hat{\gamma}_p kWh/y_i \tag{6}$$

$$\Delta q^i = \hat{\beta}_q + \hat{\gamma}_q kWh/y_i \tag{7}$$

and consider three alternative ways to define ex-ante and ex-post prices (p)and quantities (q)

(a) 2006-2007 baseline:	$x_0^i = \overline{x}^i_{2006-07} - \frac{1}{2}\Delta x^i$	$x_1^i = \overline{x}^i_{2006-07} + \frac{1}{2}\Delta x^i$
(b) 2004-2006 baseline:	$x_0^i = \overline{x}^i_{2004-06}$	$x_1^i = \overline{x}^i_{2004-06} + \Delta x^i$
(c) 2007-2009 baseline:	$x_0^i = \overline{x}^i_{2007-09} - \Delta x^i$	$x_1^i = \overline{x}^i_{2007-09}$

where $x \in \{p, q\}$ and $\overline{x}^i_{200x-0y}$ indicates the average monthly (quantity q or price p) in years $200x$ to $200y$. Because each washer entered and exited the market at different periods of time, we modify the price/quantity estimation slightly to accommodate washers that were sold only before or only after the 2007 policy change. For example, if washer models were introduced to the market after 2007, the ex-ante price (p_0^i) estimate would be zero under scenario (b), and the ex-post price could be expressed as max $\left\{0, p_0^i + \Delta p^i\right\}$. Thus, all derived prices and quantities are truncated at zero, which assume free disposal and existence of a choke price above which no sales occur.

In Table 4 we report lower-bound changes in consumer surplus, as measured in dollars per month, under the three baseline scenarios, two model specifications, and two sample sizes as described in the previous sections. The values differ in accordance with the data sample used (limited or full sample), the regression model from which changes in quantities and prices were derived (basic or robust regression), and the baseline prices and quantities used.

8 Discussion

We can estimate some, but not all, welfare effects of the 2007 changes in energy efficiency and Energy Star standards using panel regression techniques and a regression discontinuity design that exploits changes in prices and quantity that occur around the time of the policy change. Our analysis suggests that the standard changes reduced prices and increased quantities of more-efficient units, and reduced quantities and slightly increased prices of less-efficient units, some of which were banned from manufacture in 2007 but still sold after 2007.

Table 4: Estimates of Minimum Change in Consumer Surplus

Baseline Price and Quantity	Full Sample Basic Model	Full Sample Robust Model	Limited Sample Basic Model	Limited Sample Robust Model
	Dollars Per Month/ (Percent of Total Sales)			
$\bar{p}$ & $\bar{q}$ equal average of 2006 & 2007	21,294,870 (16)	13,351,420 (10)	7,690,026 (9)	5,822,681 (7)
p_0 & q_0 equal average of 2004-2006	22,666,290 (16)	14,455,160 (10)	10,373,450 (8)	8,500,414 (6)
p_1 & q_1 equal average of 2007-2009	49,551,780 (18)	27,722,650 (11)	3,810,619 (9)	2,775,854 (7)

Notes: The table reports lower bound changes in consumer surplus as described in the text, measured in dollars per month. The values differ according the sample of data used (limited of full), the regression model from which changes in quantities and prices were derived (basic or robust), and the baseline prices and quantities used. The numbers in parenthesis give the minimum change in surplus as a percent of average sales, where the denominator is $\frac{1}{2}(p_0q_0+p_1q_1)$ and p_0, q_0, p_1 and q_1 are as defined in the text.

Because the policy change would have increased demand for the more-efficient units, the observed fall in prices would seem possible under two scenarios: (a) there are significant economies of scale in production, which caused average production costs to decline with higher sales; and (b) washer markets are imperfectly competitive, and the policy change caused not just an outward shift in demand for higher efficiency units, but a change in the elasticity of demand for higher efficiency units. In the latter case, it is easy to imagine that the new demand for higher efficiency units would be more elastic to price than the previous demand would have been. Specifically, the new much larger pool of high-efficiency shoppers may have preferences that are less brand specific or feature specific than buyers of high-efficiency washers before the policy change. A more elastic demand could incite monopolistically competitive producers to lower prices. Of course, a combination of these two explanations may also account for the changes we observed in the more efficient washer market.

Other factors likely changing around the time of the policy change might bias these inferences. The most logical alternative explanation for the decline in prices is the rapid slowdown in the housing market and the aggregate economy, which also took place around this time. The resulting downward shift in demand could have encouraged firms to generally lower prices. This explanation, however, cannot reconcile the strong shift in the share of sales toward more-efficient washers. In general, we see larger growth in sales and larger declines in prices for higher efficiency units as compared to less-efficient units. This pattern cannot be easily reconciled by a general inward shift in demand due to a slowing housing market or broader economy.

Another possibility is that a technological advance in the production of relatively more-efficient machines occurred simultaneously with the policy. If this were the case, then the policy may not have *caused* the decline in price, but the advance would nevertheless have made the welfare costs of the policy change much smaller. Yet another possible explanation for the increasing demand is that rising energy prices in 2007 and 2008 precipitated higher demand for high-efficiency washers. But even if energy prices were more responsible than the policy change for the shift in demand away from low-efficiency units and toward higher efficiency units, the observed decline in washer prices would only seem possible if there were significant economies of scale, changes in strategic pricing, or both by monopolistically competitive firms. Thus, the effect of the policy would be much the same as the change in energy prices.

We have attempted to control for all these possible confounding factors described previously by using a fixed-effect model that incorporates a flexible time-trend function. The market would usually take some time to adjust and react to the anticipated policy change; hence, the time trends may be capturing effects of the policy, not just potential confounding factors. Thus, even our lower-bound estimated welfare impacts may be conservative. Indeed, when robust washer-type-specific trends are included, estimated minimum consumer surplus gains decline sharply, especially in the full sample. Yet even with these more conservative estimates we find consumer gains to be equal to at least 6 percent of total sales.

In general, these results are difficult to reconcile with the idea that the policy change caused significant welfare losses and are consistent with plausible scenarios in which the policy change improved consumer welfare. However, due to the basic challenges of identification described previously, it is not possible to use these data to estimate the impact of the policy change on firm profits.

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