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# THE EFFECT OF U.S. ELECTRICITY PRICES ON THE PURCHASE OF ENERGY-EFFICIENT APPLIANCES AND IMPLICATIONS FOR THE EFFECTS OF CARBON PRICING

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# ABSTRACT

This paper provides an empirical analysis of the long-run market shares of four ENERGY STAR (ES) appliances in the United States: refrigerators, dishwashers, clothes washers, and room air conditioners. We relate state-level market shares to electricity prices, demographics, and energy efficiency. We then use the results to estimate how a carbon pricing mechanism might influence the market share of ES appliances and, in turn, impact carbon emissions. The empirical evidence suggests that the elasticity of ES market shares to electricity prices is 0.34 or less. A carbon price expected to add at most $0.04/kWh to electricity prices would have only a modest effect on the market share of energy efficiency appliances and in turn, carbon emissions. The carbon price would reduce carbon emissions by 100,000 mWh per year, equivalent to removing 10,000 cars from U.S. roads.

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# The Effect of U.S. Electricity Prices on the Purchase of Energy-Efficient Appliances and Implications for the Effects of Carbon Pricing

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**Keywords** energy efficiency · appliances · electricity price · carbon emissions

## 1 Introduction

In 1992, the U.S. Environmental Protection Agency (EPA) introduced the ENERGY STAR (ES) program as a voluntary labeling program with the goal of identifying and promoting energy-efficient products "to reduce greenhouse gas emissions."[1] In 1996, EPA partnered with the U.S. Department of Energy

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[1] See https://www.energystar.gov/about/history.

(DOE) to provide information to consumers about appliances that save a designated amount of energy over otherwise comparable models. The ostensible goal of the program was to encourage consumers to consider purchasing more expensive energy efficient appliances.

While higher electricity prices and the savings generated by more efficient appliances should provide incentives for consumers to choose more efficient appliances, consumers do not incorporate external benefits such as reduced emissions, and so purchase fewer energy-efficient appliances than would be considered socially efficient. In addition, there is a lively debate about the existence of an energy efficiency gap, indicating that consumers discount energy efficiency savings using an above-market discount rate. If this gap exists, it would further reduce the purchase of energy-efficient appliances below the socially efficient level. There are additional economic and behavioral reasons why energy efficiency may be sub-optimal, including differing tenant/owner incentives, and impatience of low-income consumers.[2] [3]

On the surface, the ES program appears to be a relatively modest government intervention in the market for household appliances. By providing consumers with information about energy efficiency, the intervention might have the positive impact of reducing the demand for electricity, reducing any emissions associated with electricity generation, and thereby reducing a negative externality associated with energy consumption. In particular, energy efficiency is often cited as an indispensable tool to reduce carbon emissions so as to mitigate climate change. However, the extent to which the ES program impacts electricity demand, and in turn carbon emissions, is an empirical question that has not been fully investigated.

This paper empirically investigates the relationship between state-level market shares of ES appliances and state-level electricity prices, demographics, and overall energy-efficiency awareness. The estimation results are then used to simulate the indirect impact of increased market share of ES appliances on carbon emissions if a carbon-pricing mechanism were implemented in the United States. In contrast to most previous studies that rely on surveys,

[2] Davis (2010) performs an empirical assessment of the landlord-tenant problem using data from the 2005 Residential Energy Consumption Survey (RECS). Tenants may have a weaker incentive than landlords to invest in energy efficiency, given a variety of reasons including short tenancy, lack of ownership in the property, and possibly master-metering where the landlord and not the tenant pays the energy bill. Davis finds that renters are 1% to 10% less likely to report having ES appliances in their homes than owners (other than room air conditioners, which renters typically own), controlling for income, energy rates, weather, and other factors.

[3] Tsvetanov and Segerson (2014) also use RECS data, and focus on refrigerators. They find that society would gain from making only energy-efficient refrigerators available; low income consumers gain from not having to be tempted by the short-term gratification of purchasing low-cost, inefficient refrigerators – the temptation effect – as well as avoiding the disutility from self-control required to not give in to temptation. The authors find the gains in utility from lower-income consumers exceed any losses by higher income consumers caused by a restricted appliance choice.

we use data describing state-level purchases of four types of ES appliances: refrigerators, dishwashers, clothes washers, and room air conditioners.[4]

To preview our results we find that the market shares for these four ES appliances are positively related to electricity prices, higher average education, home ownership, energy-efficiency awareness, and incentives in the form of rebates. However, the response to electricity prices is highly inelastic which suggests that a modest carbon-pricing mechanism would have a muted impact on appliance purchases and in turn, a very modest impact on carbon emissions associated with electricity production.

## 2 Data Description and Empirical Methodology

ES appliance sales are reported to the U.S. Energy Information Administration (EIA) by various national retail chains, whose combined sales represent 70% of the appliance retail market although the retailers who submit data vary from year to year. In this study we focus on four common appliances that are included in the ENERGY STAR program: refrigerators (RF), clothes washers (CW), dishwashers (DW), and room air conditioners (AC).

The market share of each of these four ES appliances ranges from 29 to 59 percent based on the ten-year average for 2000 through 2009. According to the EIA, total U.S. residential electricity consumption is approximately 1,500 terawatt hours per year, resulting in approximately 750 million metric tons of carbon emissions.[5] Full market penetration of ES appliances could potentially reduce energy consumption by 64 billion kWh per year and reduce annual carbon emissions by 32 million metric tons (EIA, 2013), or just over 4% of annual emissions.

As of the year 2000, the average length of first ownership of appliances was 14.1 years for refrigerators, 12.7 years for clothes washers, 11.5 years for dishwashers, and 9.6 years for room air conditioners (Association of Home Appliance Manufacturers, 2001). Assuming current ownership patterns are roughly the same, at the current U.S. mean residential electricity price of 11.8 cents/kWh, an ES unit would save the average household $12.39 annually for refrigerators, $1.42 for dishwashers, $21.59 for clothes washers, and $14.75 for room air conditioners, resulting in savings of $114.64, $12.08, $199.80, and $114.85 respectively over the life of each unit (discounted using an annual rate of 3%). Given a typical price premium of $50 for an ES room air conditioner, $65 for a refrigerator, and $150 for a clothes dryer (U.S. Department of Energy, 2009), the payback period is approximately 4 years for an ES room air conditioner, 8 years for an ES clothes washer, and 6 years for an ES refrigerator. Table 1 contains appliance lifetimes and other appliance information.[6]

[4] Allcott and Greenstone (2012) point out that most research in this space uses survey data, which is subject to well-known biases.

[5] See EIA, U.S. Energy-Related Carbon Dioxide Emissions, http://www.eia.gov/environment/emissions/carbon/

[6] Indications are that the life expectancy of appliances is decreasing. A 2007 report by the National Association of Home Builders and Bank of America Home Equity estimated

While the electricity savings from an ES dishwasher can only cover some of the premium, rebates as well as water savings over non-ES dishwashers may help consumers recoup their initial investment. Rebates are also available for refrigerators and clothes washers, but rarely for room air conditioners. Like ES dishwashers, ES clothes washers also benefit from water savings in addition to electricity savings. However, unlike dishwashers, clothes-washer electricity savings represent a much larger savings over comparable non-ES clothes washers, at least 183 kWh per year (U.S. Department of Energy, 2012).

The U.S. Energy Information Administration (EIA) annually collects data on residential electricity rates at the state level. These rates varied from 6.3 to 32.4 cents/kilowatt hour (kwh) in 2009, which we hypothesize will lead to differences among the various U.S. states in the percentage of ES appliances purchased. Figure 1 compares the trend in mean U.S. electricity prices and the market shares of the four ES appliances from 2000 through 2009. The figure shows little consistency between rising electricity prices and increasing market share. Figure 2 shows scatter plots of ES appliance market shares against mean residential electricity prices for 2000 through 2009. The plots suggest a weak, but positive relationship between the two variables. However, the absence of a strong pattern in Figure 1 and the weak positive relationships in Figure 2 suggest that other factors may affect the market shares of ES appliances.

Economic intuition as well as the literature suggests that income, awareness of the benefits (and costs) of energy efficiency decisions, and financial incentives might influence the decision to purchase an ES appliance.[7] Thus, we gathered state-year per-capita income from the U.S. Bureau of Economic Analysis. It is anticipated that ES refrigerators, ES clothes washers, and ES dishwashers are normal goods, that is, their market shares are positively related to per-capita income. It is less clear whether room air conditioners are truly normal goods as households with higher incomes might move from room air conditioners to central air conditioning. However, conditional on purchasing a room air conditioner, it is anticipated that an increase in income is associated with purchasing more energy-efficient models.

It has been documented in previous studies that home owners are more likely to purchase ES appliances than tenants (Davis 2010). Home owners find it easier to internalize the benefits of the ES appliances if the appliances themselves influence the sale price of the housing unit and if tenants move more frequently. To test whether ES market shares are influenced by home ownership patterns, we gathered state-year data for the percent of housing units that are owner occupied from the U.S. Census Bureau.

It is also possible that those with more education are more aware of the costs and benefits (both private and social) of ES appliances and may be

refrigerators 13 years, dishwashers 9 years, and washing machines 10 years. Table 1 shows appliance lives for 2009 of 12 years for RF, 10 for DW, 11 for CW, and 9 for AC. Shorter appliance lifetimes would decrease electricity savings over the life of the appliance.

[7] See Hausman (1979) and also Dubin and McFadden (1984) on income, Murray and Mills (2011) on awareness as measured by the ACEEE ranking, and Datta and Gulati (2014) on incentives.

more inclined to purchase ES appliances. To test this hypothesis, we gathered state-year data for the percent of adults over age 25 with at least a Bachelor's degree from the U.S. Census Bureau. An additional variable thought to measure awareness and willingness to pay for ES appliances is the state-year energy-efficiency score created by the ACEEE (following Murray and Mills, 2011)[8] which reflects a state government's commitment to policies that support energy conservation and ostensibly reflects, at least in part, the state population's commitment to energy efficiency and conservation. We gathered this variable for all years possible in our sample period.[9]

The various states offer rebates of varying amounts for individuals who purchase ES appliances. Rebates averaged for the 10 years of data for refrigerators ranged from \$0 to \$47.47, for clothes washers \$0 to \$26.33, for dishwashers up to \$54.06, and there were very few rebates for room air conditioners.[10] We gathered the amount of the incentives for each appliance-state-year from the U.S. EPA Database for Incentives and Joint Marketing Exchange.[11]

Table 2 provides summary statistics of the variables used in the study. Residential electricity prices, average rebate amounts, and income were adjusted for inflation using the Consumer Price Index for All Urban Consumers, the broadest statistic available representing about 87% of the total U.S. population, provided by the U.S. Bureau of Labor Statistics. The mean market share of ES appliances by state based on the average of 2000 to 2009 ranges from about 24% to 37% for refrigerators, 53% to 65% for dishwashers, 18% to 42% for clothes washers, and 21% to 50% for room air conditioners. Resi-

[8] Murray and Mills (2011) use RECS survey data to investigate consumer awareness of the ES label and finds that certain racial and ethnic groups remain unaware of the program. They find that the American Council for an Energy Efficient Economy (ACEEE) regional score, an indicator of cultural attitude toward energy conservation, is significant in explaining awareness of the ES label. They acknowledge problems with survey data, and the possibility of selection bias where if someone noticed the ES label at all he or she may well be more in tune with efficiency. Many RECS survey respondents were not even aware whether their appliance was ES or not.

[9] The ACEEE ranks states on their adoption of energy efficiency programs and policies, including utility and public benefits programs and policies, transportation polices, building energy codes, appliance efficiency standards, and other measures. Each state is awarded points for different energy efficiency measures, with a maximum score of 50 points. The overall score is not available for all years of this study, so the means of scores from 2006, 2008, and 2009 were used in the regression. Individual state scores vary somewhat from year to year, but the relative rankings remain fairly stable, so the means of scores from three years during the time range studied were considered representative.

[10] Datta and Gulati (2014) evaluate the effect of rebates on market share of ES appliances from 2001 to 2006 and find that they have a positive effect on sales of clothes washers, but not refrigerators or dishwashers. One reason they offer is that rebates for refrigerators and dishwashers in their sample were relatively small (typically \$25 or \$50) compared to rebates for clothes washers (typically \$50 or \$100). They also note the number of rebates available for clothes washers far exceeded the number available for refrigerators and dishwashers during the time period observed.

[11] See http://www.energystar.gov/rebate-finder. The EPA is in the process of updating this database to facilitate easier use. Similar information is available at DSIRE operated by the North Carolina Clean Energy Technology Center at NC State University and funded by the U.S. Department of Energy http://www.dsireusa.org.

dential electricity price ranges from about \$0.07/kWh to almost \$0.23/kWh. Per-capita income runs from just under \$30,000 to almost \$54,000. Percent owner occupied is between 55% and 78%. The percent of the population with at least a Bachelors degree has a low of 16% and a high of 36%. ACEEE scores span 10 to 41 on a 50-point scale. Incentives begin at 0 for all three appliances where rebates are available, with the maximum for refrigerators of \$47, \$26 for dishwashers, and \$54 for clothes washers.

Given the previous discussion, the general model estimated is specified as:

$$\begin{aligned} ES_{jit} = \beta_0 + \beta_1 ElecPrice_{it} + \beta_2 PCIncome_{it} + \beta_3 PctOwnOcc_{it} + \\ \beta_4 PctBach_{it} + \gamma X_{it} + \epsilon_{it}, \end{aligned} \tag{1}$$

where the ES measures the market share of ENERGY STAR appliances of type $j$: dishwashers (DW), clothes washers (CW), refrigerators (RF), room air conditioners (AC) in state $i$ in year $t$, the $\beta$s and the vector $\gamma$ are parameters to be estimated, $\epsilon$ is a zero-mean error term, and $X$ is a matrix of additional control variables.

Our base model sets $\gamma$ to zero and estimates the relationship between ES market shares, electricity prices, per-capita income, percentage of owner-occupied homes, and the percentage of the adult population with at least a Bachelors degree. Expanding the base model entails including different additional control variables.

One extension includes regional dummy variables to control for differences in cultural attitudes toward energy conservation that could influence market share of ES appliances. Because regional dummy variables are rather coarse indicators of differences in support and interest in energy efficiency, an alternative extension includes each state's ACEEE score. A final extension includes the average rebate offered for ES refrigerators, dishwashers, and clothes washers in a state. This information was obtained from ES database for incentives and joint marketing exchange (ES, 2014).[12]

At the outset we attempted to take advantage of the longitudinal nature of the data by estimating a two-way fixed effects model and, alternatively, a random effects model. Both panel estimators performed poorly, primarily because of the very low volatility in the price of electricity within states. Because of the poor performance of the fixed effects models we instead use the so-called between estimator which uses sample means for each state. These estimates also have the additional interpretation as being long-run impacts of changes in the regressors.

[12] There were very limited rebates for room air conditioners, although they began to be introduced mid-way through 2009. Prior to 2009, only California offered rebates consistently. Given the limited number of rebates and limited variation during the study period, we excluded this variable for room air conditioners.

## 3 Results

Estimation results are reported in Table 3 through Table 6 which is divided into seven panels, one for each specification of the estimating equation. Each panel is divided into four sub-models, one for each of the ES appliances in the study: dishwashers (DW), clothes washers (CW), refrigerators (RF), and room air conditioners (AC). Using the adjusted R-squared, the various specifications explain between 32% and 73% of the variation in ES market shares, with the lowest value being that of the base model of clothes washers and the highest being that of the expanded model for refrigerators that includes both regional dummy variables and the ACEEE score. Regression diagnostics reveal no problems with non-normal, heteroscedastic, or spatially autocorrelated errors.

The relationship between market shares of ES appliances and residential electricity price is positive in twenty-four of twenty-five specifications/models and is statistically significant at the five percent level in ten of the twenty-five specifications. The relationship between electricity prices and the market share of ES refrigerators is always positive and statistically significant at the one percent level whereas the relationship is positive and statistically significant in two of four specifications for room air conditioners: the base model and the specification with only the ACEEE score added. On the other hand, the impact of electricity prices is at best only weakly statistically related to the market share of ES dishwashers; in only the base model with regional dummies included is the relationship significant at the five percent level and in only two other specifications is the relationship significant at the ten percent level. In the case of ES clothes washers the relationship between price and market share is only significant in the base model with incentives included; in all other models the relationship is insignificant at the five percent level.

The magnitude of the coefficient on electricity price ranges from 0.45 to 0.80 for refrigerators and 0.30 to 1.03 for room air conditioners. This corresponds to a range of price elasticity of market share for ES refrigerators of 0.17 to 0.30, evaluated at the means, and 0.21 for the base model. The elasticity of market share for ES room air conditioners, using the base model, is 0.34. The coefficients for dishwashers and clothes washers are also positive, but not statistically significant for the base model; elasticity of market share for ES dishwashers and ES clothes washers are 0.05 and 0.04, respectively, in the base model.

Based on the average of the coefficients for the statistically significant specifications, the elasticity for market share of ES clothes washers is 0.26, while the market share for ES dishwashers has an elasticity of 0.06. The unresponsiveness of ES dishwashers to electricity price agrees with intuition, as the electricity savings are not enough to justify paying the premium for the more efficient appliance. Air conditioners have the quickest payback period and the largest market share elasticity with respect to electricity prices, although the market share elasticity is still in the inelastic range.

As for the other variables included because they are thought to influence the perceived benefits and costs of ES appliances and therefore the market share of these appliances, the coefficient on income is insignificant in all of the specifications, which runs counter to the micro-level findings of Hausman (1979) and Dubin and McFadden (1984). It seems that differences in income within states do not explain variation in market share for the four ES appliances within the range of observed values in the U.S.

The percentage of owner-occupied housing is positive and significant at the ten percent level or better in sixteen of twenty-five models but is generally insignificant in the case of dishwashers. In the case of refrigerators and room air conditioners, the impact of owner-occupied housing is positive and significant at the five percent level in nine of twelve models entailing these appliances. These results are consistent with intuition and the literature that those who own their residence have a stronger incentive to purchase energy-efficient appliances, since they will be able to fully capitalize its value.

The percentage of a state's population with at least a Bachelor's degree is generally positively related to ES market shares and is statistically significant at the five percent level or better in eleven of twenty-five models across the four appliances. The results suggest that investments in energy efficiency increase with higher education.[13]

Adding regional dummy variables to the base model suggests that the South generally has lower market shares relative to the Northeast and the West has greater market shares relative to the Northeast (except for room air conditioners). The ACEEE score is positive and significant at the 0.05 level or better for all appliances across the three models where it is included. Finally, incentives have a positive and significant effect at the 0.05 level on the purchase of energy-efficient refrigerators and clothes washers when added to the base model. The coefficient remains positive, but is less significant when added to the models including the ACEEE score or regional dummy variables.

### 3.1 Robustness Checks

The results presented in Table 3 are marginal changes in average market shares over the ten year period of 2000 through 2009. The primary reason for using state sample means is that the electricity prices change very slowly within states and this renders the standard fixed and random effects estimators inappropriate and not well behaved.

It is of interest as to how stable the parameter estimates are across the distribution of market shares. Are market shares more sensitive to electricity price changes at the lower end of the distribution or at the higher end? We apply quartile regression models to all of the specifications reported in Table

[13] Whether this relationship is because of increased numeracy or increased awareness and concern for the private and public consequences of energy consumption and energy generation is not identifiable with the aggregate date utilized here but would be a useful extension in future research.

3. We do not report the results here for brevity, but we find that the parameter estimates on electricity prices, per-capita income, percent of housing owner-occupied, and the percent of the population with a Bachelor's degree are all relatively stable when statistically significant.

Two additional robustness checks were to cluster the standard errors by region of the country and, alternatively, by the first two digits of the state's average ACEEE score. In both cases there are only a few instances where statistical significance was reduced materially. This suggests that the results are not being driven by correlations in the error terms, either across geographic region of the country or across similar attitudes toward the environment.

## 4 Policy Implications

According to the Energy Information Agency, the residential sector in the U.S. will consume 29% of baseline energy in 2020 and accounts for 35% of end-use efficiency potential (McKinsey & Co., 2009). The McKinsey estimates use an engineering approach to calculate the potential for energy savings, and some critics point out that expected gains from investment in efficiency often fail to materialize because of improper installation, user error, unobserved costs, and rebound effects. Yet the potential efficiency gains from reducing residential energy use are so large that engineering estimates should not be discounted entirely.

A large body of economic research finds that there are market failures that lead to underinvestment in energy efficiency. The challenge is in identifying and implementing successful policies that correct these market failures and result in the economically efficient level of investment and increase overall welfare.

There is a well-developed literature on the "energy-efficiency gap," which finds that consumers underinvestment in energy efficiency.[14] The explanations may be founded on market failure explanations such as lack of information, uncertainty about future energy prices, and credit market inefficiencies. Or they may be based on behavioral failures such as consumer myopia, bounded rationality, and temptation and self-control limitations of low-income consumers (Tsvetanov and Segerson, 2014).

There are a variety of other potential market failures beyond the energy-efficiency gap, including asymmetric information on the part of consumers and the perception of not being able to capitalize energy efficiency into property values (Palmer, Walls, and Gerarden, 2012). Rebound effects where consumers use more energy because of increased efficiency (Davis 2008) are not a market failure, but do lessen potential energy savings.

[14] The energy efficiency gap, caused by consumers applying an above-market discount rate to energy-efficiency savings, is the most cited reason for an under-investment in energy efficiency. Hausman (1979) examined consumer choice among air conditioners that varied in purchase price and energy efficiency, while Dubin and McFadden (1984) looked at residential heating systems. Both papers found implied discount rates in the range of 15 to 25 percent. More recent studies, such as Parry, Evans, and Oates (2014) have also found evidence of an elevated discount rate.

The results in Table 3-6 show that the price elasticity of demand for ES appliances using the base model are 0.34 for room air conditioners, 0.21 for refrigerators, 0.05 for clothes washers, and 0.04 for dishwashers. Given these rather inelastic responses, even a large increase in electricity prices might not increase market shares of these four appliances by very much. Resources for the Future (2010) estimates an increase in residential electricity rates resulting from various carbon pricing policies would be no more than 4 cents/kWh in the most extreme scenario, while other estimates are lower because they assume a shift toward cleaner alternatives in the long run. Using 4 cents/kWh as an upper-bound of price increases, combined with baseline estimates of the electricity price elasticity for each appliance and data for 2009, the average market share for ES room air conditioners would increase from 41.4% to 46.2%, for ES refrigerators from 33.4% to 36.0%, for ES clothes washers from 37.0% to 37.6%, and for ES dishwashers from 79.3% to 79.7%.

Table 7 shows the reduction in emissions due to ES appliances based on 2009 market shares before and after the introduction of a hypothetical carbon price that adds 4 cents/kWh. The decrease in energy use from the four ES appliances translates to just under 2,000,000 MWh per year, of which just over 100,000 MWh is due to the 4 cent/kWh carbon price. Using the approximation that each MWh of electricity generated emits 0.5 metric tons of carbon, the carbon price would reduce annual total carbon emissions by just under 1,000,000 metric tons, of which about 50,000 MWh is due to the 4 cent/kWh effect of the carbon tax.

According to the EIA (2012), the U.S. emitted 5.290 billion metric tons in 2012. Thus, the total percentage reduction is approximately 0.02% per year, or 0.2% over ten years due to the carbon price, assuming average appliance life. The annual reduction in carbon emissions is the equivalent of taking just over 200,000 cars off the road, based on the U.S. EPA estimate that the typical automobile has tailpipe emissions of 4.7 metric tons of carbon.[15] Of this total, about 50,000 metric tons are due to the carbon tax, the equivalent of a little over 10,000 cars per year. In all, the ES program has a modest effect on carbon reductions, and the impact of a carbon tax would have a relatively small marginal indirect contribution through the ES program.

## 5 Conclusions

This study estimates the effect of residential electricity prices, per-capita income, the share of owner-occupied homes, and the share of adults with a Bachelor's degree on the market shares of four ES appliances in the U.S. The results suggest the market share of ES appliances show an inelastic response to electricity prices, while also responding to the share of adults with a Bachelor's degree, the percent of homes that are owner occupied, cultural attitudes, and incentives in the form of rebates.

[15] http://www3.epa.gov/otaq/climate/documents/420f14040a.pdf

The estimation results suggest that the four market shares are relatively unresponsive to variation in residential electricity prices. In turn, a carbon price on the order of \$0.04 per kilowatt hour would increase market share by less than 5% for room air conditioners, 4% for refrigerators, and even less for clothes washers and dishwashers. Overall, such a price increase would reduce carbon emissions through these four appliances by 0.02% annually and 0.2% using ten years as the average appliance lifetime. The carbon tax accounts for about 5% of the total reduction in carbon emissions. We offer a final observation concerning the results presented here. It is possible there are threshold effects involved, such that if electricity prices were to rise above a psychologically important level, their effect on market share of ES appliances would become nonlinear thereby increasing the net impact of the program on emissions. This possibility suggests a question for future research.

**Table 1** Representative Statistics for ENERGY STAR Appliances

| | RF | DW | CW | AC | Total |
|---|---|---|---|---|---|
| Average Life (Years) | 12 | 10 | 11 | 9 | – |
| Annual Sales of ES[a] | 6585000 | 5072000 | 4856000 | 4411000 | – |
| Total Appliance Sales | 19715569 | 6395965 | 13124324 | 10654589 | |
| Electricity Consumption Per Year[b] | 474 | 295 | 145 | 706 | – |
| Electricity Saving Over Base Line Per Year (kWh/yr)[c] | 53 | 12 | 183 | 125 | – |
| Total Electricity Consumption Reduction if All Sales are ES (MWh/yr) | 1044925 | 76752 | 24017513 | 1331824 | 4855252 |
| Reduction in Carbon Emissions Per Year (metric tons/yr) | 522463 | 38376 | 12008766 | 665912 | 2427626 |

[a] 2009 data

[b] These are minimum required consumption levels under 2013- 2014 standards (2007 for AC)

[c] These are for years 2012-2014. Baseline is federal minimum standard for a given, non-ES, appliance's annual electricity consumption. Figure for refrigerator reflects increased Federal standard for all refrigerators, revised upward in 2014. Number used in paper for RF is larger, reflecting lower Federal standard in 2009.

**Table 2** Descriptive Statistics

| | All States 2000-2009 (500 obs.) | | | | State Means (50 obs.) | | |
|---|---|---|---|---|---|---|---|
| Variable | Mean | Std Dev | Min. | Max. | Std Dev | Min. | Max. |
| | ENERGY STAR market share | | | | | | |
| Refrigerator | 29.02 | 8.21 | 10.54 | 57.21 | 3.03 | 24.28 | 36.5 |
| Dishwasher | 59.39 | 27.01 | 3.9 | 99 | 2.76 | 53.17 | 65.03 |
| Clothes Washer | 28.88 | 13.84 | 3.26 | 60.04 | 6.01 | 18.18 | 42.21 |
| Air Conditioner | 34.54 | 14.84 | 4.09 | 69.81 | 6.31 | 21.11 | 49.99 |
| | Incentives (2009 Dollars) | | | | | | |
| Refrigerator | 3.75 | 12.67 | 0 | 85.18 | 9.85 | 0 | 47.47 |
| Dishwasher | 2.33 | 9.11 | 0 | 53.21 | 5.95 | 0 | 26.33 |
| Clothes Washer | 3.86 | 14.68 | 0 | 113.57 | 9.83 | 0 | 54.06 |
| Air Conditioner | – | – | – | – | – | – | – |
| Residential electricity price (cents/kWh, 2009 dollars) | 10.71 | 3.29 | 6.39 | 32.38 | 3.16 | 7.09 | 22.8 |
| Per capita income (2009 dollars) | 37,672 | 5,496 | 26,866 | 57,787 | 5,330 | 29,919 | 53,656 |
| Percent of households owner occupied | 70.22 | 4.88 | 53.4 | 81.3 | 4.73 | 54.81 | 78.17 |
| Percent of population with Bachelor's degree | 26.25 | 4.63 | 15.3 | 38.2 | 4.53 | 16.37 | 36.26 |
| ACEEE Scores | 14.85 | 10.33 | 0 | 50 | 10.01 | 0.67 | 41.17 |

**Table 3** Base Models

| | Base Model | | | | Base Model with Regional Dummy | | | |
|---|---|---|---|---|---|---|---|---|
| | DW | CW | RF | AC | DW | CW | RF | AC |
| Electricity Price | 0.029 | 0.291 | 0.517*** | 1.033*** | 0.336** | 0.2 | 0.756*** | 0.474 |
| Per Capita Income | -0.004 | 0.076 | -0.048 | 0.066 | 0.029 | 0.098 | -0.005 | -0.039 |
| Percent Owner Occupied | 0.006 | 0.115 | 0.149* | 0.432** | 0.105 | 0.299** | 0.271*** | 0.308 |
| Percent with Bachelors | 0.417*** | 0.693** | 0.338*** | 0.489* | 0.334*** | 0.429** | 0.230** | 0.474* |
| South | – | – | – | – | 0.099 | -8.295*** | -0.868 | -6.461** |
| West | – | – | – | – | 3.291** | 1.427 | 3.204*** | -6.086* |
| Midwest | – | – | – | – | 2.535** | -2.706 | 1.125 | -2.866 |
| ACEEE Scores | – | – | – | – | – | – | – | – |
| Average Incentives | – | – | – | – | – | – | – | – |
| Constant | 47.838 | -3.377 | 5.95 | -22.172 | 37.218 | -6.25 | -4.614 | 0.974 |
| Adjusted R2 | 0.422 | 0.322 | 0.495 | 0.391 | 0.606 | 0.652 | 0.702 | 0.442 |

Dependent variable is Percent ENERGY STAR
*** denotes significance at 0.01 level
** denotes significance at 0.05 level
* denotes significance at 0.10 level

**Table 4** Base Models

| | Base Model with ACEEE | | | | Base Model with ACEEE & Regional Dummy | | | |
|---|---|---|---|---|---|---|---|---|
| | DW | CW | RF | AC | DW | CW | RF | AC |
| Electricity Price | -0.027 | 0.151 | 0.454*** | 0.919*** | 0.282* | 0.103 | 0.706*** | 0.296 |
| Per Capita Income | -0.02 | 0.034 | -0.067 | 0.032 | 0.008 | 0.06 | -0.024 | -0.107 |
| Percent Owner Occupied | 0.057 | 0.244 | 0.207*** | 0.537*** | 0.124* | 0.333** | 0.288*** | 0.370** |
| Percent with Bachelors | 0.311*** | 0.425 | 0.216* | 0.269 | 0.270*** | 0.314 | 0.172* | 0.264 |
| South | – | – | – | – | 0.384 | -7.777*** | -0.605 | -5.521* |
| West | – | – | – | – | 2.923** | 0.759 | 2.864** | -7.300** |
| Midwest | – | – | – | – | 2.781** | -2.259 | 1.352 | -2.054 |
| ACEEE Scores | 0.115*** | 0.289*** | 0.131*** | 0.237** | 0.088** | 0.159** | 0.081** | 0.289*** |
| Average Incentives | – | – | – | – | – | – | – | – |
| Constant | 46.556 | -6.592 | 4.487 | -24.809 | 37.553 | -5.641 | -4.304 | 2.081 |
| Adjusted R2 | 0.507 | 0.433 | 0.592 | 0.457 | 0.649 | 0.679 | 0.733 | 0.538 |

Dependent variable is Percent ENERGY STAR
*** denotes significance at 0.01 level
** denotes significance at 0.05 level
* denotes significance at 0.10 level

**Table 5** Base Models

| | Base Model with Incentives | | | | Base Model with Incentives & ACEEE | | | |
|---|---|---|---|---|---|---|---|---|
| | DW | CW | RF | AC | DW | CW | RF | AC |
| Electricity Price | 0.092 | 0.796** | 0.698*** | – | 0.004 | 0.596* | 0.599*** | – |
| Per Capita Income | 0.037 | 0.147 | 0.011 | – | -0.003 | 0.107 | -0.02 | – |
| Percent Owner Occupied | 0.053 | 0.355* | 0.237*** | – | 0.068 | 0.365** | 0.250*** | – |
| Percent with Bachelors | 0.356*** | 0.472* | 0.192* | – | 0.301** | 0.383 | 0.153 | – |
| South | – | – | – | – | – | – | – | – |
| West | – | – | – | – | – | – | – | – |
| Midwest | – | – | – | – | – | – | – | – |
| ACEEE Scores | – | – | – | – | 0.101** | 0.155** | 0.091** | – |
| Average Incentives | 0.104* | 0.282*** | 0.114*** | – | 0.038 | 0.212 | 0.079** | – |
| Constant | 43.696 | -23.607 | -0.947 | – | 45.184 | -20.332 | 0.143 | – |
| Adjusted R2 | 0.454 | 0.475 | 0.593 | – | 0.5 | 0.49 | 0.626 | – |

Dependent variable is Percent ENERGY STAR
*** denotes significance at 0.01 level
** denotes significance at 0.05 level
* denotes significance at 0.10 level

**Table 6** Base Models

| | Base Model with Incentive & Regional Dummy | | | |
|---|---|---|---|---|
| | DW | CW | RF | AC |
| Electricity Price | 0.331* | 0.436 | 0.794*** | – |
| Per Capita Income | 0.039 | 0.11 | 0.011 | – |
| Percent Owner Occupied | 0.112 | 0.371** | 0.287*** | – |
| Percent with Bachelors | 0.318*** | 0.355* | 0.176* | – |
| South | -0.017 | -7.685*** | -0.951 | – |
| West | 2.960** | 0.103 | 2.460* | – |
| Midwest | 2.388* | -2.018 | 1.067 | – |
| ACEEE Scores | – | – | – | – |
| Average Incentives | 0.037 | 0.161** | 0.056* | – |
| Constant | 36.897 | -12.986 | -5.334 | – |
| Adjusted R2 | 0.601 | 0.686 | 0.715 | – |

Dependent variable is Percent ENERGY STAR
*** denotes significance at 0.01 level
** denotes significance at 0.05 level
* denotes significance at 0.10 level

**Table 7** Reduction in Carbon Emissions due to ES Appliances (2009 data)

| | ES Sales | Average Mkt Share | Total Appliance Sales per Year |
|---|---|---|---|
| RF | 6,585,000 | 33.40% | 19,715,568 |
| DW | 5,072,000 | 79.30% | 6,395,964 |
| CW | 4,856,000 | 37% | 13,124,324 |
| AC | 4,411,000 | 41.40% | 10,654,589 |
| Total | 20,924,000 | – | 49,890,447 |

| | Increase in ES Market Share after 4 cent/kWh Price Increase | Average Mkt Share after Electricity Price Increase | ES Quantity after Electricity Price Increase | Total Electricity Saved per Year (kWh) | Increase in ES Quantity Per Year | Total Electricity Saved Per Year with Carbon Price (kWh) |
|---|---|---|---|---|---|---|
| RF | 2.60% | 36.00% | 7,097,604 | 376,173,054 | 512,604 | 27,168,054 |
| DW | 0,4% | 79.70% | 5,097,583 | 61,171,006 | 25,583 | 307,006 |
| CW | 0.60% | 37.60% | 4,934,745 | 903,058,508 | 78,745 | 14,410,508 |
| AC | 4.80% | 46.20% | 4,922,420 | 615,302,536 | 511,420 | 63,927,536 |
| Total | – | – | 22,052,354 | 1,955,705,105 | 1,128,355 | 105,813,105 |

| Total Electricity Saved after Price Increase (MWh) | Resulting Emissions Abatement (tons) | Total US Emissions in Tons (in 2012) | Reduction in Emissions |
|---|---|---|---|
| 1,955,705 | 977,852.60 | 5,290,000,000 | 0.02% |

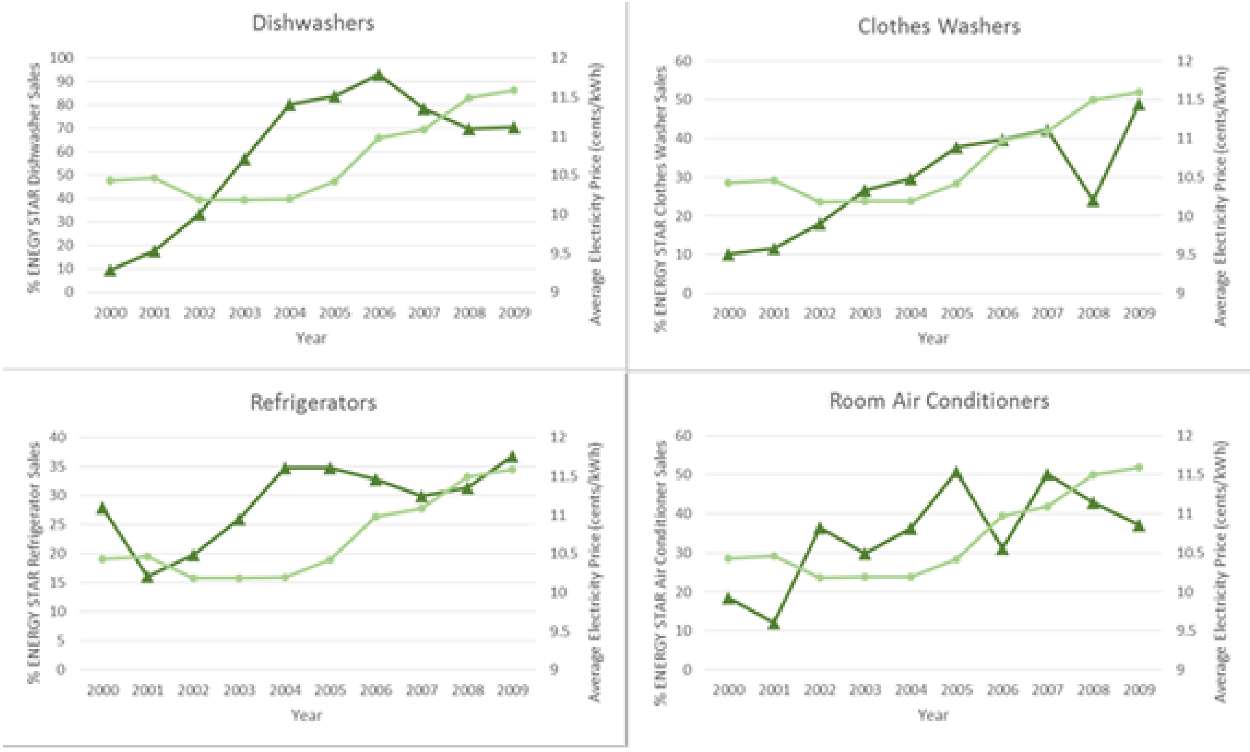


**Fig. 1** Market Shares and Residential Electricity Price (cents/kWh) over Time

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## REFERENCES

Allcott, Hunt and Michael Greenstone. (2012). Is there an energy efficiency gap? Journal of Economic Perspectives, 26(1), 3-28.

Association of Home Appliance Manufacturers. (2001). Bulletin #7: Major home appliance saturation and length of first ownership. Downloaded from www.aham.org.

Datta, Souvik and Sumeet Gulati, (2014). Utility rebates for ES appliances: Are they effective? Journal of Environmental Economics and Management. Volume 68, Issue 3, November 2014, 480-506.

Davis, Lucas W. (2008). Durable goods and residential demand for energy and water. The RAND Journal of Economics, 39(2), 530-546.


**Fig. 2** ES Market Shares and State Average Residential Electricity Price (cents/kWh)

Davis, Lucas W. (2010). Evaluating the slow adoption of energy efficient investments: Are renters less likely to have energy efficient appliances? Working paper for the Energy Institute at HAAS (U.C. Berkeley).

Dubin, Jeffrey A. and Daniel L. McFadden. (1984). An econometric analysis of residential electric appliance holdings and consumption. Econometrica, 52(2), 345-362.

Gillingham, Kenneth. (2014). Bridging the energy efficiency gap: Policy insights from economic theory and empirical evidence. Review of Environmental Economics and Policy, Volume 8, Issue1 18-38.

Hausman, Jerry A. (1979). Individual discount rates and the purchase and utilization of energy-using durables. The Bell Journal of Economics, 10(1), 33-54.

McKinsey & Co. (2009). Unlocking Energy Efficiency in the U.S. Economy. Downloaded from www.mckinsey.com.

Murray, Anthony G. and Bradford F. Mills. (2011). Read the label! ES appliance label awareness and uptake among U.S. consumers. Energy Economics 33(2011), 1103-1110.

Palmer, Karen, Margaret Walls, Todd Gerarden. (2012). Borrowing to Save Energy: An Assessment of Energy-Efficiency Financing Programs. Washington, DC: Resources for the Future.

Parry, Ian W.H. and David Evans and Wallace E. Oates. (2014). Are energy efficiency standards justified? Journal of Environmental Economics and Management, Elsevier, vol. 67(2), pages 104-125.

Resources for the Future and the National Energy Policy Institute. (2010). Toward a New National Energy Policy: Assessing the Options. Washington, D.C.: Resources for the Future.

Tietenberg, Tom and Lynne Lewis. (2012). Environmental and Natural Resource Economics, Ninth Edition, Pearson Publishing Company.

U.S. Department of Energy. (2009). Refrigerator Market Profile. Retrieved from apps1.eere.energy.gov.

U.S. Energy Information Administration. (2012) Monthly Energy Review.

U.S. Energy Information Administration, (2013). Electric Power Annual. Retrieved from http://www.eia.gov/electricity/annual/.

U.S. Environmental Protection Agency ES. (2014). Database for Incentives and Joint Marketing Exchange. http://www.energystar.gov/rebate-finder