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Consumers' Response to State Energy Efficient Appliance Rebate Programs†

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Through an evaluation of the 2009 Recovery Act's State Energy Efficient Appliance Rebate Program, this paper examines consumers' response to energy efficiency rebates. The analysis shows that 70 percent of consumers claiming a rebate were inframarginal and an additional 15 percent–20 percent of consumers simply delayed their purchases by a few weeks. Consumers responded to rebates by upgrading to higher quality, but less energy-efficient models. Overall the impact of the program on long-term energy demand is likely to be small. Measures of government expenditure per unit of energy saved are an order of magnitude higher than estimates for other energy efficiency programs. (*JEL* D12, H31, H71, Q48)

Over the past 40 years, policymakers have implemented an array of instruments—regulatory mandates, information campaigns, and technology subsidies—to promote energy efficiency. For energy-consuming durables, it is quite common that an individual consumer purchases a product designed under an energy efficiency standard, marketed subject to government-required information disclosure, and eligible for a subsidy. For example, an individual buying a Chevrolet Volt in 2017 contributed to General Motors's compliance with Department of Transportation Corporate Average Fuel Economy standards, likely learned of the fuel savings of the plug-in hybrid from the vehicle's Environmental Protection Agency (EPA) fuel economy label, and benefited from a Federal tax credit administered by the Internal Revenue Service. Likewise, large appliances are subject to federal minimum energy efficiency standards, information disclosure on typical annual energy usage, and occasionally various kinds of local, state, and federal rebates and tax credits. Given scarce resources and the existing overlay of policy instruments, what is the incremental impact of energy efficiency subsidies on energy outcomes?

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To address this question, we evaluate the State Energy Efficient Appliance Rebate Program (SEEARP), commonly referred to as "Cash for Appliances" (C4A). As a part of a suite of programs funded through the 2009 Recovery Act aimed at promoting investment in energy-efficient durables and equipment (Aldy 2013), state governments received \$300 million to subsidize the purchase of energy-efficient residential appliances. A consumer could claim a rebate under a state's C4A program if she purchased an appliance with an ENERGYSTAR (ES) rating—one of the federal government's information programs for appliances that assigns a label to appliances that meet specific energy efficiency requirements. The states had considerable discretion in the design and implementation of their C4A programs, resulting in significant heterogeneity across the country in the timing, subsidy amount, and appliance category eligibility.

Using transaction-level data from a large national retailer, we estimate the impact of C4A rebates on the sales of refrigerators, clothes washers, and dishwashers. We find that state C4A programs increased appliance sales 7 to 10 percent during the rebate period for these three appliance categories. The market share of ES-rated appliances—those eligible for the rebates—increased 1 to 2 percent during the rebate period. A 2 percent increase in the ES share of the refrigerator market during the rebate period, however, resulted in a statistically significant but economically minuscule effect on refrigerator energy efficiency. Consumers claiming rebates for refrigerator purchases through the state C4A programs could expect to consume about 2 kilowatt hours less per year based on appliance energy efficiency ratings.

We quantify the behavioral response to rebates along three dimensions: (i) substitution from non-eligible products toward eligible products, (ii) intertemporal substitution, and (iii) upgrading toward higher quality products. We find that about 70 percent of consumers who claimed a rebate would have bought an ES-rated appliance during the period of the C4A program in the absence of the rebates. An additional 15 percent to 20 percent of consumers changed the timing of their purchase of an ES-rated appliance by a few weeks. Expanding our analysis from the rebate period to also include each of the three months before and after the rebate period results in precise, statistical zero impacts for sales, ENERGYSTAR market share, and appliance energy efficiency. Altogether, about 90 percent of consumers who claimed a rebate do not contribute to an improvement in the energy efficiency of purchased appliances.

Our finding on the importance of intertemporal substitution for energy-consuming durables is consistent with the research on the Cash for Clunkers program. Mian and Sufi (2012); Li, Linn, and Spiller (2013); and Hoekstra, Puller, and West (2014) each found significant intertemporal shifting under Cash for Clunkers: a large share of program participants moved forward their car purchase decision by a few months. For a different type of subsidy, Sallee (2011) also found that consumers shifted the timing of the purchase of the Toyota Prius to maximize their tax benefits.

We also find that rebates led consumers to upgrade toward higher quality, but less energy-efficient models. Upgrading reflects the focus of the rebate programs on ES certification. Specifically, the ES certification requirement is a function of minimum efficiency standards for appliances, which are less stringent for larger appliances (and can be less stringent based on other valued appliance attributes). For example, a large refrigerator with a given level of energy efficiency could qualify for the ES label, but a smaller refrigerator with the same level of energy efficiency might not. We show that holding utilization constant, the interaction between subsidies and minimum energy efficiency standards results in a particular case of attribute-based regulation (Ito and Sallee 2014) that induces perverse upgrading. Finally, we also find some evidence that the generous rebates may have induced an income effect that led consumers to upgrade toward higher quality, but larger size models.

The design and implementation of the C4A program facilitate our empirical analysis. First, the Federal government allocated funds to the states on a per capita basis; thus the "size" of this stimulus program, at the state level, is exogenous of the states economic condition in 2009 and 2010. Our identification strategy is similar to that of other papers that have estimated the economic impacts of Recovery Act programs implemented through formula-based allocations (Wilson 2012; Chodorow-Reich et al. 2012). Second, the state discretion in program design resulted in significant heterogeneity in terms of start dates, eligible appliance categories, rebate amounts, and other characteristics. We combine this rich source of variation with unique micro-data on individual appliance sales aggregated to the week-state level. Our main estimators rely on a difference-in-differences strategy and accounts for state-year unobservables. We also provide extensive robustness tests that show that pre-existing time trends and sorting into the program are not a threat to the internal validity of our main estimates.

As a part of the 2009 Recovery Act, C4A had dual purposes: stimulating economic activity and improving the energy efficiency of purchased appliances. The C4A program was a relatively small fraction of Recovery Act spending (less than 1/20 of 1 percent), which precludes direct statistical analysis of its impact on economic activity. While transferring approximately \$300 million to households contributed to the overall economic stimulus effort, the disbursement was not necessarily quick by Recovery Act standards; only one state distributed rebates in 2009. Moreover, the high free-riding rate suggests little opportunity for leveraging private investment, an important impact of other Recovery Act energy programs (Aldy 2013).

Our findings offer a cautionary tale to federal, state, and local program managers designing energy efficiency programs to promote cost-effectiveness and maximize their net social benefit. We show that for C4A, the cost per kilowatt-hour saved is on the order of about \$0.21 to \$1.10, depending on assumptions and appliance category. The low end of this range is four times the average cost per unit of energy saved by utility-sponsored energy efficiency programs (Arimura et al. 2012). The very large proportion of inframarginal participants explains this result. Our free-riding estimates are similar to the Boomhower and Davis (2014) estimates for a large-scale energy efficiency rebate program for refrigerators and air conditioners in Mexico as well as the Alberini, Gans, and Towe (2016) estimates for a Maryland energy-efficient heat pump rebate program.

The remainder of the paper proceeds as follows. Section I describes the appliance efficiency policy landscape and presents a framework for evaluating energy efficiency subsidy instruments. Section II presents the data. Section III presents our empirical strategy. Section IV describes our results. Section V investigates whether the program induces an income effect and upgrading. Section VI presents a policy analysis of the cost-effectiveness of C4A and counterfactual policy scenarios. Conclusions follow.

I. Appliance Efficiency Policy Landscape

Since the oil shocks of the 1970s, local, state, and federal governments have employed an array of policy instruments to promote the energy efficiency of appliances (and energy efficiency more generally). The 1975 Energy Policy and Conservation Act established a national energy conservation program, including EnergyGuide labels for residential appliances. These labels inform consumers about the energy characteristics of a given appliance and its market competitors. Specifically, the labels provide expected annual energy use, which serves as the energy efficiency measure in our empirical work below.

The 1987 National Appliance Energy Conservation Act authorized the Department of Energy to promulgate minimum efficiency standards for appliances. In 1992, the Environmental Protection Agency (EPA) launched the ENERGY STAR (ES) program, a voluntary initiative for appliance manufacturers (and others) to demonstrate the energy efficiency of their products. An appliance model can earn the ES label, a simple brand-like logo, if its energy efficiency level exceeds by a certain percentage the minimum standard for that appliance category.

The ES certification played an important role in the design of the C4A program. The program was funded by an appropriation in the 2009 Recovery Act and authorized as the State Energy Efficient Appliance Rebate Program in the Energy Policy Act of 2005. The 2005 law establishes the objective of this program as "provid[ing] rebates to residential consumers for the purchase of residential ENERGY STAR products to replace used appliances of the same type" (42 USC 15821). The law was later amended to allow for more stringent eligibility criteria that go beyond the ES certification requirement.[1] Table 1 summarizes the rebate eligibility criteria used for the three appliance categories that we study. Most states allocated rebates for products that just met the ES certification, although for clothes washers and dishwashers several states adopted more stringent efficiency criteria.

The 2005 law also requires the federal government to allocate funds to state programs proportional to each state's share of the national population. States have discretion over the design of several elements of their rebate programs. As a result, the C4A program gave rise to 50 unique state programs that differed in the rebate amounts offered, appliances covered, eligibility criteria, timing and duration, and mechanisms to claim the rebates.

Under C4A, the states offered economically significant rebates, on average, 12 percent–15 percent of sales prices for refrigerators, dishwashers, and clothes washers, and these varied greatly among states.[2] Most states offered a fixed lump-sum rebate

[1] The more stringent eligibility criteria must, however, be defined with the same formula used to set the ES certification requirement. That is, they must be defined relative to the energy efficiency levels set by the federal minimum standards.

[2] Figure A.1 in the online Appendix plots the average price paid along with the average rebate amount claimed across states for these different appliances.

Table 1—Rebates and Eligibility Criteria for Each State

	Refrigerators		Clothes washers		Dishwashers	
	Rebate	Criteria	Rebate	Criteria	Rebate	Criteria
AK	300–600	ES (rural)	300–600	ES	300–600	ES (rural)
AL	150	ES	100	ES	75	ES
AR	275	ES	225	ES	—	
AZ	200–300	ES	125–200	ES & above	75–125	ES & above
CA	200	ES	100	Above ES	100	Above ES
CO	50–100	ES	75	ES	50	Above ES
CT	50	ES	100	Above ES	—	
DE	100	ES	75	ES	75	ES
FL	20%	ES	20%	ES	20%	ES
GA	50	ES	50–99	ES & above	50–99	ES & above
HI	250	ES	—		—	
IA	200–500	ES	200	ES	200–250	ES & above
ID	75	ES	75	ES	50	ES
IL	15%	ES	15%	ES	15%	ES
IN	—		—		—	
KS	700	ES (low)	800	Above ES	400	Above ES
KY	50	ES	100	ES	50	ES
LA	250	ES	100	ES	150	ES
MA	200	ES & above	175	ES	250	ES & above
MD	50	ES & above	100	ES	—	
ME	—		—		—	
MI	50–100	ES & above	50	ES	25–50	ES & above
MN	100	ES	200	ES	150	ES
MO	250	ES	125	ES	125	ES
MS	75	ES	100–150	ES & above	75–100	ES & above
MT	100	ES	100	ES	50	ES
NC	15%	ES	100	ES	75 or 15%	ES
ND	150	ES	—		—	
NE	200	ES	100–200	ES & above	150	Above ES
NJ	75–100		35	ES	25–50	ES & above
NM	200	ES	200	ES	—	
NV	200	ES	150	ES	100	ES
NY	75–105		75–100	ES & above	165	ES
OH	100	ES	150	ES	100	ES
OK	200	ES	200	ES	—	
OR	70%	ES (low)	70%	ES	70%	ES
RI	150	ES	—		150	ES
SC	50	ES	100	ES	50	ES
SD	150	ES	100	ES	75	ES
TX	175–315	ES	100–225	ES & above	85–185	ES
UT	—		75	ES		
VA	60	ES	75–350	ES & above	50–275	ES & above
VT	75	ES	150	ES	—	
WA	75	ES	150	ES	75	ES
WI	75	ES	100	ES	25	ES
WV	100	ES	50–75	Above ES	50–75	ES & above
WY	—		100	ES	50	ES

Notes: Criteria using ENERGY STAR have the acronym ES. "Above ES" means that a criteria more stringent than ES was used and "ES & above" means that both the ES criterion and a more stringent criterion was used. Alaska offered different rebate amounts for rural and non-rural residents. Oregon limited rebates to low-income households whose income was at or below 60 percent of state median income. Kansas also limited rebates to low-income households.

amount for a qualifying purchase, but four states, Florida, Illinois, North Carolina, and Oregon, offered ad valorem rebates.

State programs also varied in the timing of their implementation. On July 14, 2009, DOE issued a press release announcing the program and allocation of funds to the states. State governments began to draft design and implementation plans for

C4A, which they submitted to DOE for review and approval. According to Google Trends, consumers first started to search for the program in June 2009. In August 2009, search queries rapidly increased and appear to be correlated with ABC News's national story comparing the program with Cash for Clunkers (August 20, 2009). States began advertising their programs in November and December 2009. The first program started the second week of December 2009 in Kansas. By April 2010, more than 80 percent of the states had launched their C4A programs. The programs lasted 26 weeks on average, although program duration was quite heterogeneous, with some programs open less than a week (Iowa), while Alaska's program lasted 91 weeks. Some states had "1-day programs" that reflect the fact that all appliance rebates had been reserved through advanced reservation systems by the end of the first day. Actual purchase dates occurred over longer periods of time.

Consumers could claim a rebate, typically through online and mail options, by providing proof of purchase of an eligible appliance and residency. Some states established a reservation system where consumers could reserve rebates prior to going to the store. Most states did not offer rebates for online purchases. Rebates were limited to one for each appliance category, but several states allowed households to claim multiple rebates. Kansas, Ohio, Oregon, and Montana employed means-tested eligibility criteria for their rebate programs. In most states, however, all households were eligible to claim rebates for qualifying appliances. Several states provided additional incentives if the old appliance was hauled away and recycled.

We collected information about state programs—including appliances covered, rebate amount, eligibility criteria, and start and end dates—from each state's program website. We also conducted interviews with program administrators in several states to learn more about the implementation of their programs. Table 2 provides summary statistics of the program. Refrigerators, clothes washers, and dishwashers were the most common appliance categories covered by the C4A programs and they accounted for 85 percent of the claims and 65 percent of rebate funds. In our analysis below, we focus on in-store purchases of these three appliance categories.

Overall, the C4A program resembles many utility-sponsored appliance rebate programs offered in the United States both before and after the Recovery Act. For instance, utility-sponsored programs offered in 2009 focused mostly on refrigerators, clothes washers, and dishwashers, and had similar program features and implementation details. The rebate amounts offered by utilities tended to be less generous, about 60 percent of the rebate amounts offered under C4A. Under C4A, states were required to provide some cost-sharing, which often took the form of retailer advertising. As a result, the level of consumer awareness for these programs was probably on par, or even exceeded, what is typical for utility-sponsored programs. Finally, an important commonality between utility-sponsored programs and C4A is that the ES certification also serves as the basis of eligibility for rebates. Other countries have also offered rebate programs similar in design where a certain energy efficiency level is used to determine eligibility (de la Rue du Can et al. 2014).

Using the ES certification as a basis for energy efficiency subsidies may bring a number of unintended consequences. Using a simple economic framework, we illustrate how making rebates a function of ES certification, which is itself a function of minimum efficiency standards, influences free-riding and upgrading in appliance

Table 2—Summary Statistics: Cash for Appliances

Product	States offering rebates	Claims	Amount distributed ($M)	Average price paid ($)	Average rebate claimed ($)
Air conditioners	30	70,781	25.6	4,511	361
Boilers	18	7,678	4.0	5,516	518
Clothes washers	43	580,863	62.1	698	107
Dishwashers	37	316,117	26.6	543	84
Electric water heaters	25	3,267	1.0	1,636	307
Freezers	26	24,312	2.5	579	103
Furnaces	34	76,469	30.9	5,772	404
Gas water heaters	30	15,766	2.1	703	130
Tankless water heaters	31	11,140	3.0	2,266	267
Heat pumps	26	47,470	23.6	6,403	497
Refrigerators	44	613,561	78.8	1,112	128
Solar water heaters	15	634	0.8	7,961	1,308
Total		1,768,058	260.9		

Notes: Data collected by program administrators and provided to the Department of Energy. Excludes US territories.

rebate programs. This will motivate our empirical analysis of the impact of state C4A programs.

Consider that appliance energy efficiency is measured as the ratio of the flow of appliance services to energy consumption. The federal minimum energy efficiency standards and ES certification are examples of attribute-based regulation (Ito and Sallee 2014), where the maximum amount of energy a given appliance model can consume is a function of size and other attributes. In the size/energy efficiency space, a minimum efficiency standard (MEF) and ES requirement can be represented by two downward sloping parallel lines (Figure 1), where only bundles above the minimum standard are allowed to be present on the market, and certified products are all bundles above the ES requirement. Consumers can spend their disposable income on appliances or other goods. When purchasing an appliance, each consumer values both size and efficiency. A consumer's optimal bundle thus corresponds to the point where the indifference curve (U) is tangent to the budget constraint (W). Minimum standards, the ES certification, and subsidies, however, may induce movements in both the size and efficiency dimensions. Their impact on energy savings is thus ambiguous.

Panel A of Figure 1 depicts the case where the appliance model purchased in equilibrium just meets the ES requirement, as is often the case in several markets (Houde 2014). Offering a rebate R for purchasing an ES product may induce the so-called freerider problem, a well-known source of economic inefficiency in this context (Joskow and Marron 1992). Because program administrators cannot restrict the access to a rebate program, consumers who would have purchased an ES product absent rebates can simply claim the rebate, make the exact same purchase, and spend the windfall income on other goods. It is also possible that the rebate induces a small income effect, which can be represented by an outward movement of the budget constraint. As a result, a consumer may purchase a more efficient, but also larger appliance (panel B). Depending on consumers' preferences over size and efficiency, it is possible that the income effect induces the purchase of a larger (smaller), but

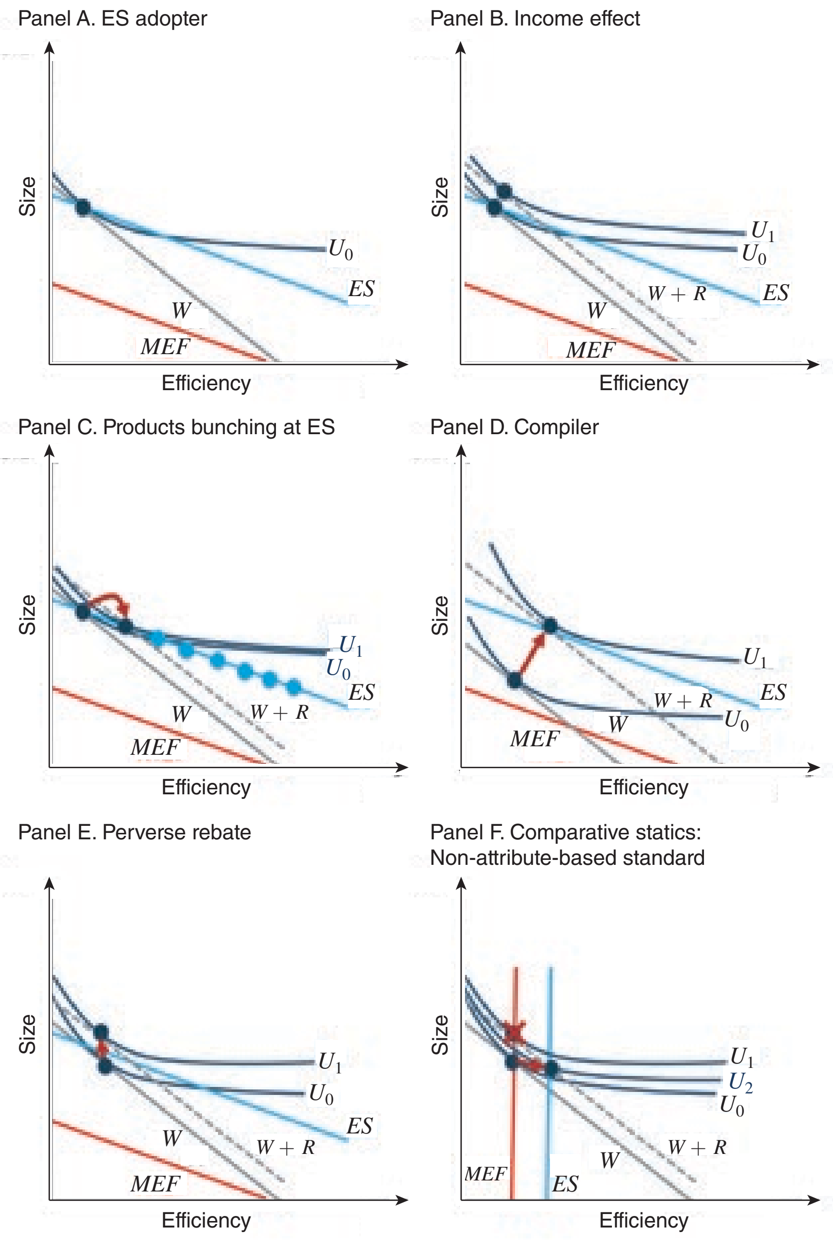

Figure 1. The Simple Economics of Energy Efficient Rebates

less (more) efficient appliance. Only in the case where firms offer products that bunch exclusively at the ES requirement will the income effect unambiguously lead to more efficient purchases (panel C).

Even for consumers who could not afford ES products in the first place, offering a rebate R does not ensure that a more efficient appliance will be purchased. Panel D illustrates the case where the rebate leads to the adoption of a more efficient and larger ES-certified appliance, relative to a non-ES-certified product. It is, however, easy to construct an example (panel E) where the rebate has a perverse effect and leads to the adoption of a less efficient product. In this example, this perverse effect can be ruled out only if the minimum standard and ES requirement are set independently of size and solely lie in the energy efficiency space (panel F).[3] More generally, rebates could yield perverse outcomes when energy efficiency and the attributes used to set the regulation are inversely correlated. In such case, rebates become implicit subsidies for specific attributes other than energy efficiency.

II. Data and Preliminary Evidence

The DOE required state program administrators to collect detailed data on their C4A programs and the department provided us a dataset that includes information on the 1.8 million rebates issued in the 50 US states. For each rebate claim, we observe product characteristics (manufacturer model number, brand, and price paid), rebate amount, the dates of the purchase and rebate application, and zip code of the household. Some states also collected information about the appliance that was replaced, whether the old appliance was hauled away, and the retailer where the purchase was made.

One limitation of the DOE data is that they only contain information about C4A participants and do not provide information to construct a valid counterfactual of participants' behavior in the absence of rebates. Thus, for our primary analyses, we rely on transaction-level data that were provided by a large retailer with non-negligible market shares ($>$ 5 percent) in the appliance market. The retailer has brick-and-mortar stores in every state and an online store. The data cover the period from January 2008 to November 2012. For each transaction, we observe the manufacturer model number of the product purchased, the location of the store, the price paid, taxes, manufacturer's suggested retail prices, and a unique household identifier. For nearly half of our transactions, we have socio-demographic data collected by a third party (Acxiom) and matched by the retailer. These data include income, education level, housing type, age of head of the household, political orientation, home ownership, and family size. We do not observe the household addresses, but we observe the location of the store where the household purchased its appliance(s); we assume that households lived in the same state where they made their purchase(s). The retailer has a national price policy, which store managers tend to follow closely. Retail prices are thus set at the national level with little idiosyncratic variation across stores. For each appliance, we observe attribute information such as expected electricity consumption, size, ES certification, and numerous other features.

A possible limitation of our analysis is that the retailer might not be fully representative of the appliance market. We can address this concern using the DOE data, which recorded the retailer where each participant made a purchase.[4] In the online Appendix, Table A.1 compares prices, rebates claimed, the expected energy

[3] Ito and Sallee (2014) show that the optimal externality-correcting tax/subsidy can be adjusted to account for the existence of attribute-based standards. Gillingham (2013) discuss similar issues in the design of a feebate policy in the presence of a fuel economy standard.

[4] Not all states recorded this information.

consumption and the size of the products purchased under C4A at our retailer versus all other retailers observed in the DOE data. We found that on average prices tend to be slightly higher, especially for refrigerators, at our retailer relative to other retailers. Except for refrigerators, there are no statistically significant differences in size. For expected energy consumption, there is no clear pattern. Overall, we found that the differences between our retailer and others to be modest. We also examine whether the consumers who shop at our retailer are representative of the consumers participating more broadly in C4A. We map the zip code of delivered appliances for C4A rebate claimants for our retailer and for all other retailers in those states that report retailer information to zip code socio-demographic data from the 2010 census. Table A.2 (online Appendix) compares median household income, average age, average household size, as well as population shares by gender, ethnicity, homeownership, educational attainment, and poverty line status. While the differences in means for the socio-demographic characteristics of shoppers at our retailer to those of shoppers at other retailers are statistically different for all but one measure (given the large sample size), these differences in magnitudes are not economically meaningful; for 9 of the 11 measures, the differences in magnitudes are less than 2 percent. We believe that these provide good support for external validity.

III. Empirical Strategy

Consumers who want to take advantage of a rebate program can do so by waiting for the start of the program or pulling forward their decision to replace their appliance during the program window. We label these consumers the *intertemporal substitutors*. When the rebate program is active, consumers can substitute among products. We define as *switchers* the consumers who substitute away from non-rebate-eligible products toward eligible products. *Non-switchers* are the consumers that claim a rebate, although they would have purchased an eligible product even in the absence of a rebate program. Some of these consumers may take advantage of rebates to substitute among eligible products and upgrade toward higher quality models. Rebates lead to expected energy savings via two mechanisms. First, consumers who pull forward their purchases accelerate the replacement of older and less efficient appliances. Note that consumers waiting for the start of a program have the opposite effect and contribute to an overall increase in energy demand by holding on to their old appliances longer.[5] Second, consumers may substitute toward more energy-efficient products.

Throughout the paper, the energy efficiency of appliance model j is measured by the expected annual energy use reported by appliance manufacturers and that appears on the EnergyGuide label. Our analysis does not consider how a particular household idiosyncratically uses energy-intensive durables and thus abstracts from potential rebound effects.

To investigate the potential for intertemporal substitution, we distinguish among four distinct time periods of a rebate program: the pre-announcement period, the

[5] In the present context, the C4A program was first mentioned in the new media in the summer of 2009 and most programs started less than a year after. Thus, the effect of delayed replacement is likely limited.

period between the announcement and the start of a rebate program (the pre-rebate period), the rebate period, and the post-rebate period. The pre-rebate period should begin at the exact time the consumer who first learned about rebates decided to wait for the start of the program. Presumably, this may have happened following the announcement of the program. Similarly, the end of the post-rebate period should be defined as the purchase date that the last consumer who decided to pull forward her purchase would have chosen if rebates had not been offered. These two consumers are not observed. Our strategy to define the beginning of the pre-rebate period and the end of the post-rebate period will then consist of conducting sensitivity analysis.

Our empirical strategy consists of looking at three outcome variables: total sales, energy efficiency (manufacturers' reported appliance energy use), and ES market shares. The effect of rebates on total sales informs us about the extent of the intertemporal substitution and how long the effects of the program lasted. The effect of rebates on energy efficiency (expected appliance energy use) determines the change in energy use of the stock of appliances purchased at the time rebates impacted consumers. Finally, looking at ES market shares allows us to distintguish intertemporal substitutors from switchers, and quantifying the number of program participants that were truly marginal to the rebate programs. In Section IV, we also use the estimates for ES market shares to determine the magnitude of the quality effects.

To determine the causal effect of rebates on each of these three outcome variables, we rely on difference-in-differences (DD) estimators that exploit variation across states in program coverage for a specific appliance category, timing of implementation, and rebate amount. To illustrate, the effect of rebates on weekly sales, for a given appliance category, in state s is estimated with the following model:

$$\log(sales_{s,t}) = \alpha_{sy} + \gamma_t + \sum_{l=t}^{T} \rho_l \cdot DPeriod_{s,lt} \cdot R_s + \epsilon_{s,t}, \tag{1}$$

where $DPeriod_{s,lt}$ is a dummy variable that takes the value one if week t falls in the period l of a rebate program. In all our regressions, we will omit the dummy variable that identifies the pre-announcement period. The rebate amount offered in state s is given by R_s, and corresponds to the rebate amount reported on the program websites. We use the same specification for the two other outcome variables: expected appliance energy use and ES market shares, which are both sales-weighted averages computed at the state-week level.

In the base specification, we assume that the marginal impact of rebates is the same across all states. We do not account for differences in eligibility criteria, mechanisms to claim rebates, or other factors that may have impacted the behavioral response to the rebates. We address program heterogeneity later. For programs that provided ad valorem rebates, we compute an average rebate amount by multiplying the percentage incentive by the average price specific to each appliance category. By interacting $DPeriod_{s,lt}$ and R_s, ρ_l measures the effect of a rebate in a particular period of the program. For instance, we can estimate the impact of rebates in the first week where rebates are offered, the week just before the start, and the week just after the end. We can also define $DPeriod_{s,lt}$ to cover the whole rebate period, and include some weeks in the pre-rebate and post-rebate periods.

The DD estimator is implemented by adding two sets of fixed effects: α_{sy} and γ_t, which are respectively state-year and week-year fixed effects. The week-year fixed effects take out the effects of promotions and advertising campaigns implemented by the retailer, seasonality, and other shocks that impact the market of each appliance type. The fact that the retailer has a national price policy implies that the week-year fixed effects capture the effect of the retailer's national pricing strategy. The dummy variables $DPeriod_{s,lt}$ are not perfectly correlated with week-year fixed effects because only a subset of states implemented rebate programs for a particular appliance category and the timing of the programs varied across states. The state-year fixed effects control for time varying state-specific unobservables that may be correlated with the design and implementation of rebate programs. They also control for rebate programs offered by state governments and/or energy utilities, which may vary from year to year and have been found to impact the ES market shares for some appliances (Datta and Gulati 2014). With state-year fixed effects, the coefficients on $DPeriod_{s,lt}$ are identified using variation in the timing of implementation of each state rebate program within the calendar year (see Figure A.2 in the online Appendix). We are thus comparing weeks in a given year where a rebate program was active to weeks in the same year, where the program was inactive. For the few states where the rebate programs covered the entire 2011 year (e.g., Alaska), identification is coming from variation in program coverage within the years 2010 and 2012 only.

The main challenge to internal validity in our empirical strategy is that the features of state rebate programs could be correlated with the impacts of the Great Recession or other time-varying shocks in each state. Previous Recovery Act program evaluations have used allocation formulas exogenous to economic conditions and state fixed effects and year fixed effects to address such concerns (Wilson 2012, Chodorow-Reich et al. 2012). In our work, we use state-year fixed effects, which provide even further controls for possible unobserved economic factors influencing our results, and exploit the fact that the allocation of funds was predetermined by the formula set in the Energy Policy Act of 2005. States had the sovereignty to determine several other features of their programs, which could have been influenced by the local economic conditions at that time. Through our interviews with the various program administrators, however, we concluded that it is unlikely that the program features adopted in each state were systematically correlated with the Great Recession. For all state program administrators, C4A represented their first experience with a large-scale rebate program. Moreover, there was no precedent at the federal level. We argue that the inexperience of the state program administrators, the absence of past examples, and the difficulty to forecast the effects of the recession as it was unfolding make the features of each state program idiosyncratic.[6] The relative timing of a state's initial plan submission, DOE feedback, negotiation over modifications, and final plan approval also appeared to be idiosyncratic.

[6] Bailey (2012) makes a similar point for her study of early US family planning programs. The large increase in federal funding on family planning in the early seventies combined with the inexperience of local organizations lead to a disorganized response to the federal grant making. As a result, the timing of new family planning programs during that period can be considered exogenous.

TABLE 3—SUMMARY STATISTICS: RETAILER'S CHOICE SET

	Appliances		
	Refrigerators	Clothes washers	Dishwashers
ES market share pre-announcement period (January–July 2009)			
Mean	46%	53%	75%
SD (across states)	8%	10%	12%
Number of models offered in 2010–2011			
ES	1,470	488	889
Non-ES	1,527	226	87
Average energy efficiency (kWh/year), 2010–2011 models			
ES	498	205	305
Non-ES	549	502	338
Average size, 2010–2011 models			
ES	27.7	3.5	2.0
Non-ES	26.6	3.2	1.4
Average promotional price ($), 2010–2011 models			
ES	1,642	954	697
Non-ES	1,859	610	573
Average manufacturer's suggested retail price ($), 2010–2011 models			
ES	1,778	1,033	764
Non-ES	1,938	643	624
Style, 2010–2011 models	Percent top-freezer	Percent top-load	
ES	18	30	—
Non-ES	27	63	—

Notes: Summary statistics for number of models, electricity consumption, size, price, and style are non-sales weighted. The metric "size" is measured in cubic feet for clothes washers and refrigerators. For dishwashers, size is defined with a categorical variable, where 1 = standard, 2 = tall, 3 = giant, and 4 = super capacity. The price corresponds to the retail price.

IV. Results

The ES program covers all three appliance categories evaluated in our study. Over January–June 2009, national ES market shares were 46 percent for refrigerators, 53 percent for clothes washers, and 75 percent for dishwashers (Table 3). Figure 2 plots the first evidence of the impact of rebates on sales, manufacturers' reported appliance energy use, and ES market shares. For ES market shares, all certified appliance models as of January 2010 are included in the market shares.

For refrigerators and clothes washers, we observe short-lived increases in ES market shares when most rebate programs were enacted. We observe similar increases in sales for all three appliance categories, which further suggests that intertemporal substitution was important. Finally, as a preview of our main results—the correlation between the number of active programs and appliance energy efficiency appears to be weak, especially for dishwashers and refrigerators.

We first present the main results graphically. Figure 3 presents nonparametric estimates of the total effect of rebates on sales, appliance energy efficiency, and ES market shares over time. To construct these estimates, each outcome variable was first normalized with a regression with state-year and week-year fixed effects. The residuals of this regression, which we refer to as the outcome variable normalized, were then regressed on flexible regression splines counting the number of

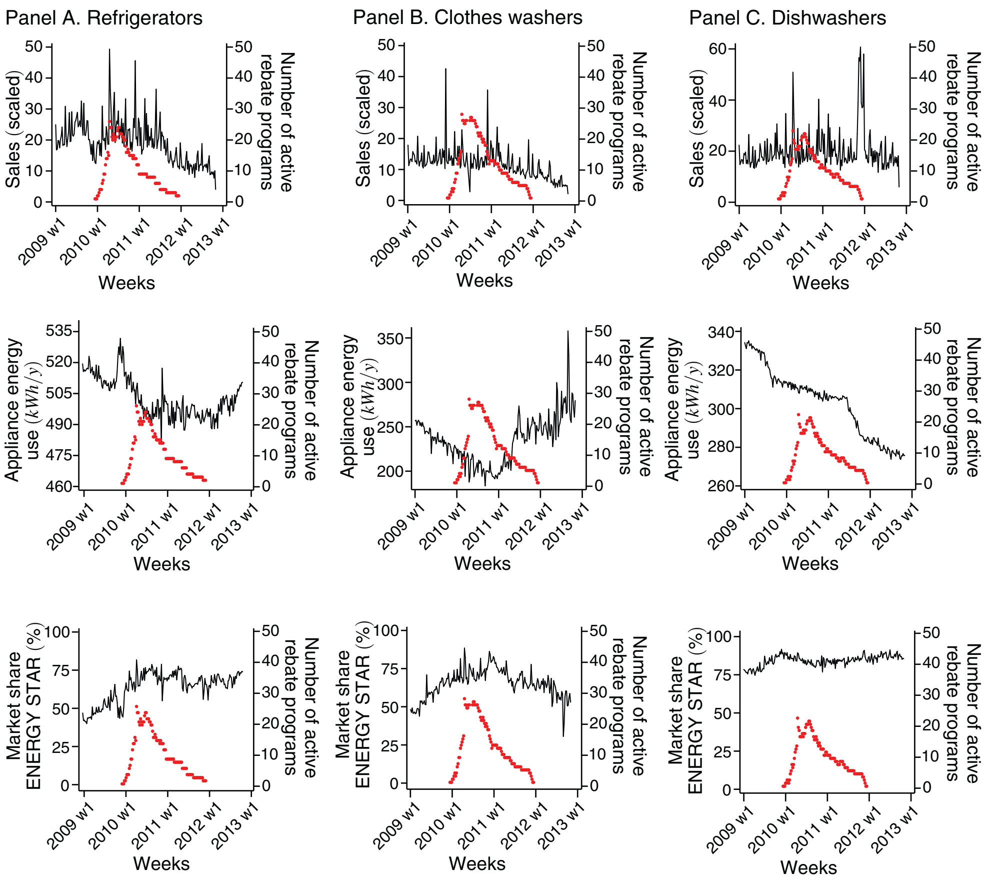

Figure 2. Number of Active Rebate Programs versus National Averages: Sales, Energy Efficiency, and ENERGY STAR Market Shares

Notes: Each panel shows a weekly national average compared to the number of active state rebate programs. Total weekly sales are scaled by a factor such that levels are not disclosed. Appliance models that were ES certified as of January 1, 2010 are included in the ES market share for the whole time horizon.

weeks since the start of a rebate program. Each panel plots the estimated splines—smoothed time-varying estimates of the effect of rebates as a function of time.

The first row of Figure 3 shows the effect of rebates on sales for all three appliance categories. We observe economically and statistically significant, but short-lived increases concentrated in the first two weeks after the start of the rebate programs.[7] The estimates show that these increases are largely driven by consumers delaying their purchase decisions by a few weeks. We observe statistically significant reductions in sales beginning approximately one to two months before the start of the programs. In the online Appendix (Figure A.3), we show that the impact on sales in the post-rebate period is modest and not statistically significant for all three appliance categories. The regression results from equation (1) (Table A.3) are consistent

[7] To put the magnitude of these increases in context, the average weekly variation in state sales, for the three appliance categories we consider, is exactly 50 percent.

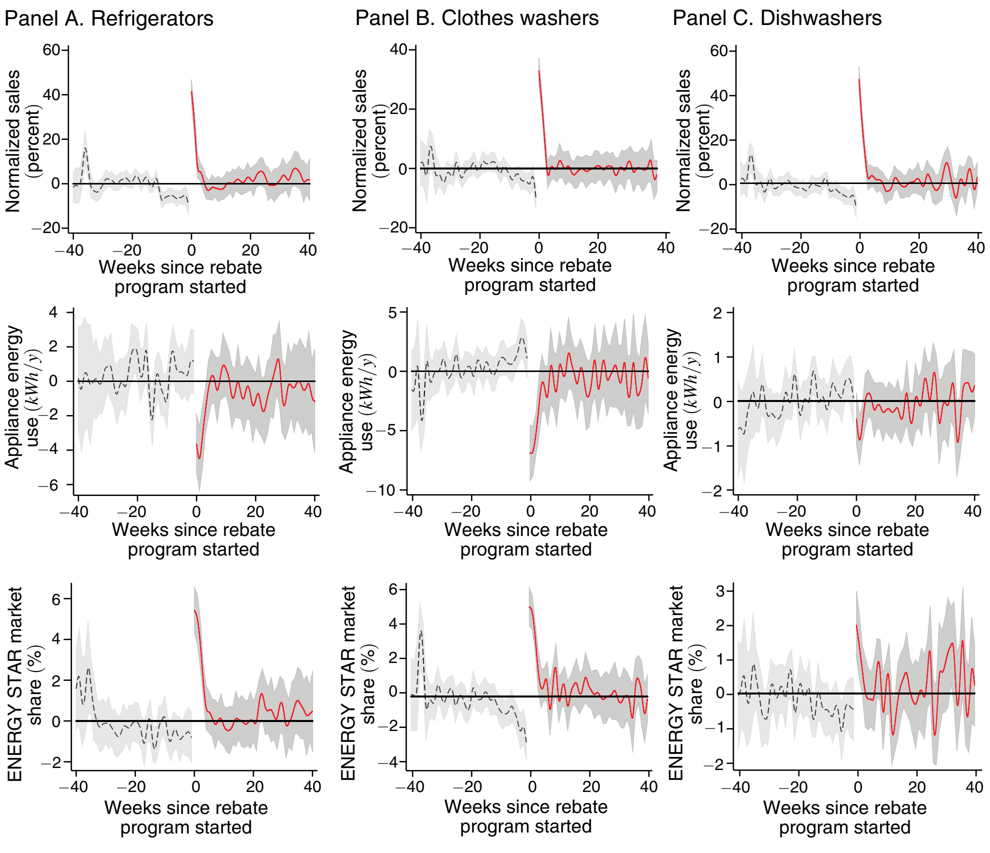

FIGURE 3. SALES, ENERGY EFFICIENCY, AND ENERGY STAR MARKET SHARE SINCE PROGRAM START DATE

Notes: The figure shows normalized sales, appliance energy use (kWh/y), and ES market share. All three outcome variables are normalized using a regression that removes week-of-sample and state-year fixed effects. The figure presents a fitted spline and the 95 percent confidence interval. The positive part of the *x*-axis corresponds to the number of weeks since a rebate program started.

with the graphical evidence. For refrigerators, a \$100 rebate leads to an increase in sales of 14 percent in the first week of a program, relative to the pre-announcement period, but this increase is offset by statistically significant reductions that range from 2.2 percent to 3.9 percent up to nine weeks preceding the start of the program. For clothes washers, a \$100 rebate leads to a 10 percent increase in sales in the first week, which is offset by a decrease of 4.9 percent in the week just prior. The results are qualitatively similar for dishwashers. We detect a statistically significant increase in sales only in the first week of a rebate program, but decreases in the pre-rebate period are found up to nine weeks before the start of a program. In the post-rebate period, the estimates are not statistically significant for two appliance categories.[8] For dishwashers, we detect a decrease in sales several weeks (more than ten) after

[8] As discussed by House and Shapiro (2008), this result is to be expected for temporary stimulus programs. Future demand reductions for durables should be spread over a long period of time after the end of a short-lived stimulus program, making it hard to detect reductions.

Table 4—The Marginal Effect of Rebates on Sales, Appliance Energy Efficiency, and ES Market Share

	I. Rebate period only			II. Rebate period, 2 months pre-, 2 weeks post			III. Rebate period, 3 months pre-, 3 months post		
Dep. var.:	log(sales)	log(kWh)	ES	log(sales)	log(kWh)	ES	log(sales)	log(kWh)	ES
Refrigerators									
Est.	0.10	−0.0035	0.021	0.012	−0.00018	0.0024	0.0085	0.00013	−0.00031
SE	(0.021)	(0.001)	(0.005)	(0.006)	(0.0003)	(0.002)	(0.005)	(0.0005)	(0.001)
Observations	12,450	12,450	12,450	12,450	12,450	12,450	12,450	12,450	12,450
R^2	0.995	0.901	0.915	0.995	0.901	0.914	0.995	0.901	0.914
Clothes washers									
Est.	0.067	−0.017	0.021	0.0097	−0.0017	0.00087	0.007	−0.00029	−0.00063
SE	(0.016)	(0.004)	(0.005)	(0.003)	(0.001)	(0.001)	(0.004)	(0.001)	(0.001)
Observations	12,100	12,100	12,100	12,100	12,100	12,100	12,100	12,100	12,100
R^2	0.996	0.936	0.917	0.996	0.936	0.916	0.996	0.936	0.916
Dishwashers									
Est.	0.096	−0.00056	0.0073	0.021	−0.00015	−0.00026	0.0024	−0.00014	−0.0007
SE	(0.018)	(0.000)	(0.003)	(0.007)	(0.0003)	(0.001)	(0.005)	(0.0003)	(0.002)
Observations	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
R^2	0.995	0.989	0.766	0.995	0.989	0.765	0.995	0.989	0.766

Notes: The dummy variable for the pre-announcement period is omitted. The rebate amount is measured in hundreds of dollars. A coefficient of 0.10 thus implies that a $100 rebate leads to a 10 percent increase. Standard errors (in parentheses) are clustered at the state level. All specifications have week-of-sample and state fixed effects.

the program ended. Our results contrast with the findings of Mian and Sufi (2012) who found that the Cash for Clunkers program led to a significant decrease in sales in the post-rebate period. In the present case, we also find evidence of an important short-term intertemporal substitution, but some consumers waited a few weeks to replace their current appliance instead of pulling forward their purchase decisions.

Table 4 further quantifies the importance of short-term intertemporal substitution in the present context. If we estimate the marginal effect of rebates on sales during the whole rebate period, we find that a $100 rebate would increase sales, relative to the pre-announcement period, by 10 percent, 6.7 percent, and 9.6 percent for refrigerators, clothes washers, and dishwashers, respectively. If we estimate the marginal effect during the rebate period plus two months of the pre-rebate period and two weeks of the post-rebate period, the size of the marginal effect ranges from only 1 percent to 2 percent. Once we include more time in the pre-rebate and post-rebate periods, e.g., three months before and after the start of the programs, the effects disappear.[9] This suggests that most consumers who participated in the rebate programs would have still replaced their appliances in the year that the rebates were offered. The overall stimulus effect of the program was then modest: it leveraged little incremental private investment, although it did provide a means for transferring resources to households who participated in the program.

[9] In fact, if we estimate the marginal effect of rebates for the first week of the rebate period and also include the pre-rebate period starting from the announcement date, we find no statistically significant effects. This reinforces the point that most of the short-term increase in sales came from short-term substitution.

Turning to the effect of rebates on energy efficiency, the graphical results (second row, Figure 3) mirror the effect on sales. The appliances purchased during the rebate programs are more energy-efficient, on average, but statistically significant effects are only found in the first week of the programs. For dishwashers, the rebates had very small effects on energy efficiency, no greater than 1 kWh/yr savings even in the first week of the program. For refrigerators and clothes washers, there is a more substantial short-term effect, on the order of 5–7 kWh/yr, but this effect rapidly fades off. Table 4 (section I.) shows that over the entire rebate period, the improvement in refrigerator energy efficiency is statistically significant but economically small (about 0.35 percent, or less than 2 kWh/year). For clothes washers, there is a statistically significant improvement of 1.7 percent, and for dishwashers the estimate is close to zero and not statistically significant. Once we include the pre-rebate and post-rebate periods, the estimates converge to zero and are not statistically significant for all three appliance categories.

The estimates for ES market shares show that most program participants did not substitute from non-ES to ES models, and some consumers simply substituted the timing of their purchase of an ES model. Although we find large increases in ES market shares in the first week of the programs (third row, Figure 3), we find no effect once we account for the pre-rebate and post-rebate periods (Table 4, sections II. and III.).

We have conducted an array of robustness tests, including analyses that control for household socio-demographic characteristics, variations in specifications of trends and fixed effects, and sample restrictions based on state C4A program characteristics. Our key findings are robust to these alternative specifications (see the online Appendix).

Heterogeneity by State.—One important feature of the legislation establishing SEEARP is that it provides sovereignty to states over the design of their rebate programs. Our empirical strategy has so far exploited variation in coverage, timing, and rebate amount across states to estimate the average treatment effect of a rebate on sales and electricity consumption, where the average was taken over all state programs. State programs under C4A, however, differed with respect to other dimensions, such as the mechanisms to claim rebates, eligibility criteria, reservation system, additional incentives for hauling away the old appliances, and expected program length. In this section, we seek to investigate heterogeneity in the effects of rebate programs across states.

Our empirical strategy is similar as before. We rely on a DD estimator to estimate a treatment effect in each state. In this specification, we use within year and across states variation in program coverage to control for state and time specific effects. Variation in rebate amounts is not a source of identification anymore given that it is confounded with other program features. Our identification then relies on the difference in the timing of the program and the fact that only a subset of states offers rebates for particular appliance categories. The model that we estimate is

$$\log(kWh_{s,t}) = \alpha_{sy} + \gamma_t + \sum_{l=t}^{T} \lambda_{l,s} \cdot Tw_{s,lt} \cdot Dstate_s + \epsilon_{s,t}. \tag{2}$$

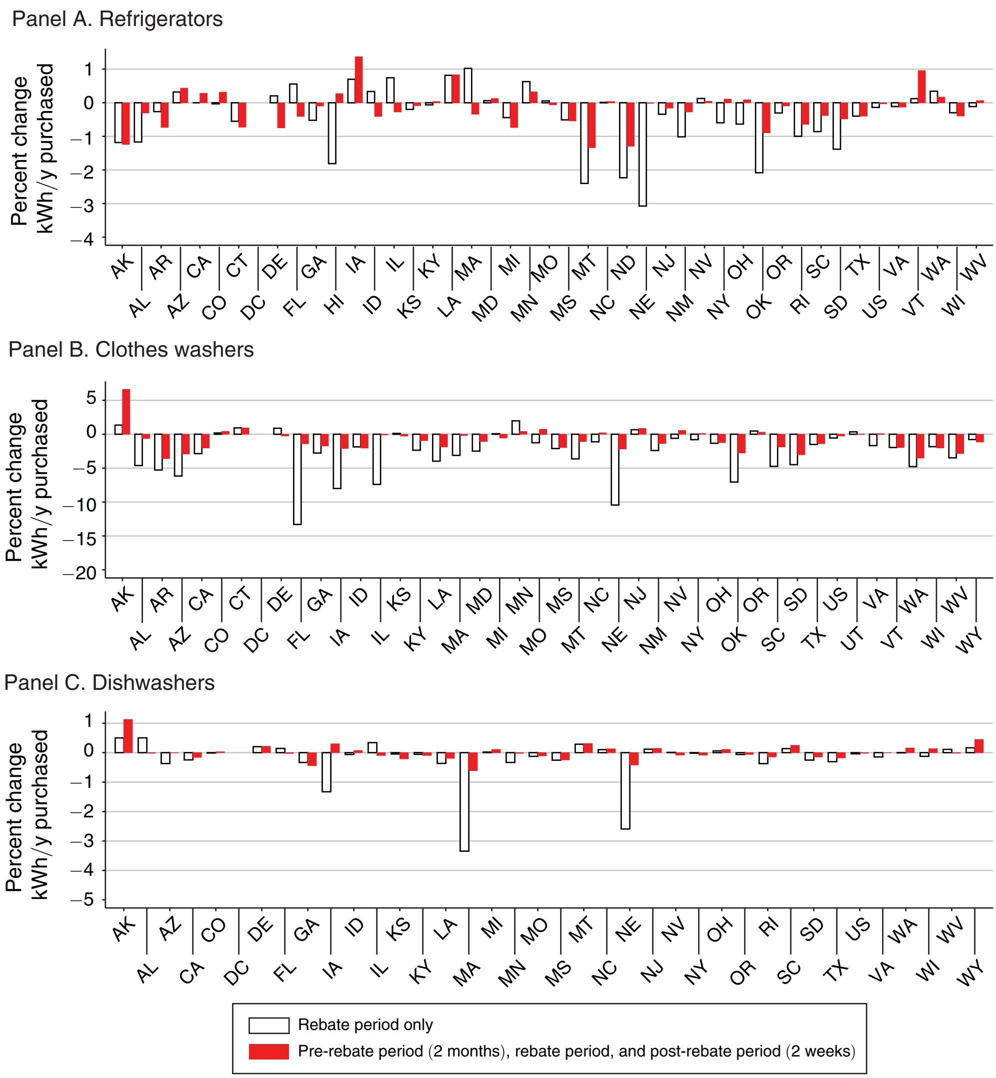

Figure 4. Impact of State Rebate Programs on Appliance Energy Efficiency by State

Notes: Each panel shows the average percentage change in expected energy use (kWh/y) of the appliances purchased during state rebate programs. For each state, two estimates are shown: the change during the rebate period only, and the change during the period that includes two months before the rebate period, the rebate period, and two weeks after the rebate period.

Figure 4 presents the estimation results graphically by illustrating the effects of rebate programs on energy efficiency. Each estimate represents a percentage change in the reported energy use of the appliances purchased relative to the pre-announcement period. We present two estimates for each state. The first estimate reflects the effect of rebate programs during the rebate period only. The second estimate accounts for the effect of intertemporal substitution. For this second estimate, the time horizon considered includes two months of the pre-rebate period and two weeks of the post-rebate period.

Overall, these findings mirror the previous results: the largest reductions in expected energy consumption are observed for clothes washers, and, accounting for intertemporal substitution, reduces the magnitude of the estimated energy savings. For each appliance category, a few states have large reductions, but for most states the estimates are close to zero.

We also investigate how program design could explain the variation among states by regressing the mean estimate for each state on a vector of program characteristics, such as the average rebate amount, program duration, whether the rebates were ad valorem or not, whether rebates could be claimed online, the existence of a reservation system, incentive or requirement for hauling away the old appliance, and the eligibility criteria. The results are presented in the online Appendix (Table A.8). More generous rebates tend to lead to larger energy savings for all appliances, except refrigerators, where the effect is not statistically significant. Offering an ad valorem rebate leads to smaller savings relative to a lump-sum rebate. Having an eligibility criterion stricter than ES contributed to larger savings for dishwashers, but not for clothes washers. Recycling incentives, which are provided if a consumer shows that the old appliance was hauled away, also had an impact for dishwashers, but not for clothes washers. We do not find statistically significant effects for other program features.

V. Upgrading

As illustrated by our theoretical framework, rebates for ES-certified appliances can induce an income effect and act as implicit subsidies for nonenergy attributes used to establish minimum efficiency standards. These two effects combined imply that consumers taking advantage of rebates may substitute toward ES-certified models that differ along several dimensions of quality relative to non-ES-certified models. In this section, we quantify the importance of these upgrading effects. We also show whether they are mainly driven by an income effect or the fact that the ES certification requirement is attribute-based.

To determine the magnitude of the upgrading effects, we compute the average treatment effect on the treated (ATET) for various dimensions of quality. In addition to energy efficiency, we report results for size, product design, and manufacturer's suggested retail price, which we consider a proxy of overall quality. In the present context, the ATET estimates the difference, in a specific dimension of quality, between the ES products purchased by program participants and the non-ES products that they would have purchased in the absence of rebates. To determine if the income effect is important, we then compare the ATET estimates to the corresponding differences in quality observed in the choice set. We argue that a large discrepancy between those two quantities suggests the existence of an important income effect. The intuition is the following. If there were no income effect, consumers taking advantage of rebates should substitute toward ES products that are the closest substitutes to the non-ES products that they would have otherwise considered. Therefore, the changes in quality induced by rebates should closely match the model-weighted differences in quality between non-ES and ES products offered by manufacturers. To illustrate, consider this simple example where manufacturers make product lines such that for each non-ES product on the market there is a corresponding ES product offered that is identical along all dimensions of quality except energy efficiency. In the absence of an income effect, a consumer taking advantage of rebates would then purchase an ES product that is identical to the non-ES product he would have purchased without rebates. In this scenario, the effect of rebates on dimensions of quality other than expected energy use should be exactly zero.

The ATET estimates can be readily obtained using the estimates presented in Section III. For instance, consider the non-parametric DD estimates of Figure 3 for refrigerators. In the first week of the rebate programs, we find an increase in the ES market share of 6 percent and an improvement in energy efficiency of 4 kWh/yr. The ATET is the implied difference in expected energy use between ES and non-ES products for program participants. This can thus be computed by dividing the change in energy use in the overall population of consumers by the change in ES market share: $4/0.06 = 67$ kWh/yr. The ATET for other dimensions of quality are computed similarly.

How should we interpret this difference of 67 kWh/yr? In relative terms, it means that ES refrigerators purchased by program participants had 12 percent lower energy use than non-ES models (547 kWh/yr, Table 3). This reduction is much smaller than implied by the 2010 ES certification requirement for refrigerators. In that year, ES refrigerators had to use at least 20 percent less energy than their corresponding minimum standards. Given that most refrigerators that are non-ES certified tend to meet exactly the minimum standard (Houde 2014), switching from a non-ES to a ES refrigerator of similar size and style should lead to a reduction in energy use close to 20 percent. Therefore, the fact that we find that the reduction in expected energy use is 60 percent of the certification requirement implies that consumers substituted toward ES refrigerators that differ along key dimensions of quality that impact overall energy use. Figure 5 confirms this. On the first row, we show the effect of rebates on MSRP. In the second and third rows, the dependent variables are overall size and door design style, respectively. For refrigerators, we observe that rebates induce consumers to purchase larger models. In the first week of the program, we detect a statistically significant increase of 0.5 percent. Given the increase of 6 percent in ES market share in that week, the implied difference in size between non-ES and ES models purchased under a rebate program is $0.005/0.06 = 8.3$ percent. Table 3 shows that manufacturers meet the ES certification by offering larger refrigerators; ES refrigerators are on average 5.3 percent larger than non-ES models. Upsizing is, therefore, likely to be driven by both the certification requirement and the income effect. If there were no income effect, the adoption of ES certified models should lead to an increase in size that closely matches the model-weighted difference (i.e., 5.3 percent). But, the fact that we observe upsizing that goes beyond what is induced by the choice set alone, suggests that the income effect plays a role here. We also find that program participants substituted away from top-freezer refrigerators to bottom-freezer or side-by-side, which tend to use more energy. More precisely, consumers that switched toward ES-certified models in the first week of the programs were 25 percent (0.015/0.06) less likely to purchase a top-freezer model.

For clothes washers, the upgrading effects are also economically important, but we find little evidence of an income effect. We observe a statistically significant

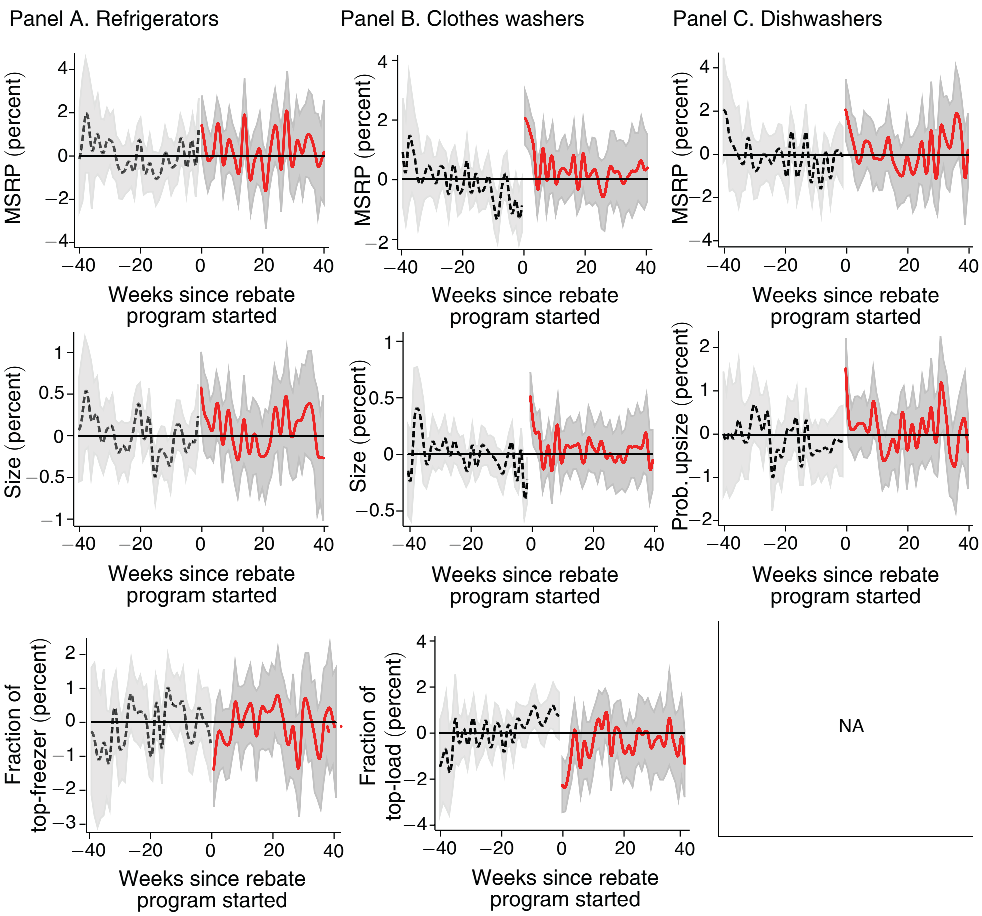

Figure 5. MSRP, Size, and Appliance Type since Program Start Date

Notes: The figure shows normalized manufacturers' suggested retail prices, appliance size, and appliance type. For refrigerators, appliance type is dummy variable that takes a value of one if this is a top-freezer and zero otherwise. For clothes washers, appliance type distinguishes among top-load and front-load washers. For dishwashers, size is a categorical variable that takes four values, where 1 = standard, 2 = tall, 3 = giant, and 4 = super capacity. All three outcome variables are normalized using a regression that removes week-of-sample and state-year fixed effects. The figure presents a fitted spline and the 95 percent confidence interval. The positive part of the *x*-axis corresponds to the number of weeks since a rebate program started.

increase in MSRP of the order of 2 percent in the first week (Figure 5). If we divide this percentage by the change in ES market share, we find that program participants purchased ES clothes washers that were 40 percent (0.02/0.05) more expensive than non-ES models, on average. This is a large increase, but less than the 60 percent difference in MSRPs between non-ES and ES clothes washers offered on the market at that time (Table 3). This suggests that program participants purchased more expensive clothes washers simply because ES models have higher MSRPs. That is, upgrading was induced by the choice set, not by the income effect. Results for size and door design (top-load versus front-load) are consistent with this interpretation. The 0.5 percent increase in size in the first week implied that program participants upsized their clothes washers by 10 percent, which is very close to the

9.4 percent difference between certified and non-certified models that were offered on the market at this time (Table 3). Regarding the door design, the ATET suggests that program participants were 40 percent less likely to purchase a top-load washer. Considering that only 30 percent of ES-certified clothes washers are top-load, but that 63 percent of non-ES models are, the higher propensity to purchase front load models during the rebate program can also be explained by the choice set offered to consumers.

Finally, for dishwashers we find that upgrading is also present and that the income effect is likely to be particularly important. Again, focusing on the estimates for the first week of the programs (Figure 5), the 2 percent increase in MSRP along with the 2 percent increase in the ES market share implies that participants bought ES dishwashers twice as expensive relative to non-ES dishwashers. It is unlikely that this large difference is entirely driven by manufacturers setting higher prices for ES-certified dishwashers—during that period, the MSRPs of ES dishwashers were only 22 percent higher, on average, relative to non-ES models (Table 3). Consumers that took advantage of rebates purchased dishwashers of much higher quality than they would have done in the absence of the programs. Figure 5 also shows evidence of upsizing. In the first week, the probability of upgrading from a standard size model to a larger increases by 2 percent. This translates to an ATET of 100 percent, which means that program participants were twice as likely to upsize their dishwashers under the rebate programs.

Overall, upgrading effects are important for all three appliance categories. The policy instruments used to establish the rebate criteria appear to be important drivers of these effects. Manufacturers offer ES models that differ systematically from non-ES models partly because the certification requirement is set as a function of non-energy attributes. As a result, we find that program participants purchased ES models that differ from non-ES along these dimensions of quality. In addition, the results for refrigerators and dishwashers reveal an income effect.

Our findings on upgrading on quality dimensions fit within a broader literature that has investigated how capital subsidies affect the quality as well as the quantity of capital purchased. For example, Bils and Klenow (2001) estimate so-called quality Engel curves that reveal substantial quality upgrading across an array of consumer durable goods categories with household income. Goolsbee (1998) finds that capital subsidies are associated with higher equipment prices, although House and Shapiro (2008) do not find price impacts from short-lived bonus depreciation policies. Since our retailer sets a national pricing policy, the changes in the prices of the appliances purchased by the consumers in our dataset reflect changes in the bundle of attributes that they are effectively purchasing in an appliance transaction. As indicated in our findings, the quality upgrading along nonenergy attributes likely explains any price effects.

VI. Cost-Effectiveness

How much is society paying to improve appliance energy efficiency? Understanding the cost per kilowatt-hour avoided can also inform consideration of pollution externalities, such as the carbon intensity of electricity (CO_2/kWh) that serves as the basis for state targets under the Environmental Protection Agency's Clean Power Plan. This would also permit a comparison of C4A's cost-effectiveness with other energy efficiency programs. To investigate this issue, we propose a simple approach to measure cost-effectiveness. The first step consists of estimating the proportion of rebate recipients that does not contribute to energy efficiency improvements. Rebate recipients fall into four categories: (i) switchers/non-intertemporal substitutors—the consumers who switched away from a non-ES product, and purchased an ES product because of the existence of rebates, but did not delay or accelerate their purchase decision; (ii) switchers/intertemporal substitutors—the consumers who switched and substituted over time; (3) non-switchers/non-intertemporal substitutors—the consumers who would have bought an ES product during the rebate program even in the absence of rebates; and (4) non-switchers/intertemporal substitutors—the consumers who did not switch, but substituted over time to take advantage of rebates. Non-switchers/non-intertemporal substitutors are the inframarginal consumers—commonly referred as the freeriders. They are non-marginal program participants that do not contribute to expected energy savings. In the present context, non-switchers'/intertemporal substitutors' contribution to energy efficiency improvement is small and possibly negative given that most simply delayed their purchase decision by a few months. To illustrate the importance of intertemporal substitution, we present two estimates of cost-effectiveness. One that only considers the proportion of inframarginal consumers and the other that considers the overall proportion of non-switchers, whether or not they are intertemporal substitutors.

A unique feature of our data is that we observe the number of rebate participants shopping at our retailer in a number of states. This allows us to quantify the take-up rate, and quantify the proportion of rebate recipients that fall in each of the four categories described above.

We integrate our national retailer data with the DOE data for the 13 states that identify the retailer in their C4A reporting. For these states, the proportion of rebate recipients is simply the total number of rebate claims divided by total sales at our retailer. The average proportion of rebate recipients across these 13 states is 11.3 percent, 14.3 percent, and 10.7 percent for refrigerators, clothes washers, and dishwashers, respectively.

To estimate the proportion of inframarginal consumers, we employ a state-specific estimator where our dependent variable is the log of total sales of ES products:

$$\log(SalesES_{s,t}) = \alpha_{sy} + \gamma_t + \sum_{s=1}^{S} \lambda_s \cdot TRebate_{s,lt} \cdot Dstate_s + \epsilon_{s,t}. \tag{3}$$

As before, the index s denotes state and t denotes week. We define the dummy variable $TRebate_{s,t}$ to take a value of one during the rebate period and zero otherwise. We use this model to estimate the increase in ES sales during the rebate period only, which is attributable to both types of switchers (i.e., intertemporal substitutors and non-intertemporal substitutors) and to non-switchers/intertemporal substitutors. We then divide this estimate by the number of rebate recipients that we observe. The proportion of inframarginal consumers is simply one minus this share, which is about 70 percent for all three appliance categories (Table 5). The proportion of

Table 5—Rebate Recipients, Inframarginal Consumers, and Non-switchers

	Rebate recipients (%)	Inframarginal consumers (%)	Non-switchers (%)
Refrigerators	11.3	71.5	92.0
Clothes washers	14.2	69.3	90.5
Dishwashers	10.7	70.6	85.9

Notes: The first column shows the proportion of rebate recipients among all consumers that purchase an appliance of a given category during the rebate period, two months prior, or two weeks after the rebate ended. The second column shows the proportion of rebate recipients that would have purchased an ES appliance without the rebate and did not change the timing of their purchase decision. Those are the inframarginal consumers. In the third column, the non-switchers are the rebate recipients that would have purchased an ES appliance without the rebate during the rebate period, just before, or after the program. Non-switchers corresponds to the inframarginal consumers and the intertemporal substitutors that delayed or accelerated the purchase of an ES product.

non-switchers can be estimated following a similar approach. The difference is that we define a dummy variable in equation (3) that includes both the pre-rebate and post-rebate periods, in addition of the rebate period, which allows us to detect the increase in ES sales that are due to switchers irrespective of the fact they substituted over time or not. The switchers' share is obtained by dividing this estimate by the number of rebate recipients, and the non-switchers' share is one minus this estimate. If we include two months of the pre-rebate period and two weeks of the post-rebate period, the non-switchers' share is 92.0 percent, 90.5 percent, and 85.9 percent for refrigerators, clothes washers, and dishwashers.

A. *Quantifying the Impact on Energy Efficiency*

The second step to perform the cost-effectiveness analysis consists of computing the impact on energy efficiency (the expected energy saved) by switchers for a given rebate eligibility criterion. We consider that for switchers the savings correspond to the difference in the model-weighted energy efficiency rating between rebate-eligible products and non-rebate-eligible products offered on the market. This approach has a number of implicit assumptions. First, it rules out income effects that would lead to upgrading, but accounts for upgrading due to the nature of the ES certification requirement, i.e., the fact that eligible products differ from non-eligible products in various dimensions of quality, in addition to energy efficiency. Second, it does not account for equilibrium effects and how manufacturers' product lines would respond to a rebate program. Finally, it abstracts from consumers' utilization decisions.

Using the estimated share of freeriders or non-switchers and the average energy saved by switchers, the energy saved by the overall population of rebate recipients is given by

$$\Delta kWh_{Recipients} = (1 - \pi) \cdot \Delta kWh_{Switchers} \cdot Lifetime, \tag{4}$$

where π is the proportion of consumers that does not contribute to energy efficiency improvement. Depending on whether one wants to account for intertemporal substitution, π corresponds to the share of inframarginal consumers or non-switchers, respectively. $\Delta kWh_{Switchers}$ is the difference in average annual energy use between rebate-eligible and non-rebate-eligible products. This difference is then multiplied by the average lifetime of the appliance. The cost-effectiveness measure that we report is the dollar amount spent for each kWh saved, which is the ratio of the rebate offered over the average lifetime energy savings achieved for the rebate eligibility criterion selected.

In our calculations, we assume a 15-year lifetime.[10] For all three appliance categories, we use data from NPD Group, a market research company, to characterize the choice set of the US appliance market for the years 2010–2011. We then use this choice set to compute the model-weighted average energy use for the actual state C4A eligibility criteria (ES-rating) and counterfactual assumptions about alternative rebate eligibility criteria. The NPD data have been used in several recent studies of the appliance market (Houde 2014; Spurlock 2013; Ashenfelter, Hasken, and Weinburg 2013). They provide monthly sales at the model level from the year 2001 to 2011 and were collected from various retailers. The NPD Group reports that their data covered approximately 40 percent of the US appliance market.

Finally, we also adjust our estimated energy savings to account for accelerated replacement of existing appliances. We first assume that all switchers replaced their old appliances five years earlier than they would have in the absence of the program. We selected five years after inspecting the manufacturing year for a subset of refrigerators that were scrapped under C4A.[11] For these replaced refrigerators, we found that the average manufacturing year was 2001 and the average electricity consumption was 639 kWh/y. Again, assuming that the average life expectancy of a refrigerator is 15 years implies that switchers may have pulled forward their replacement decision by 5 years under C4A, on average. We then compute the total amount of energy saved by taking the difference in electricity consumption of an ES-rated appliance purchased in 2010 and an appliance purchased 10 years before (in 2001). We then sum this difference over five years. For the remaining, 10 years of the appliance lifetime, the average savings are simply the difference between an ES and non ES-rated appliance purchased in 2010.

B. *Cost-Effectiveness Results*

At the average rebate amount offered for all three appliance categories, the C4A did not perform well. The dollar amount spent for each kWh saved is \$1.10 for refrigerators, \$0.21 for clothes washers, and \$0.46 for dishwashers. This substantially exceeds the cost per unit energy saved found for other utility-funded

[10] The DOE assumes a lifetime of 18 years in its regulatory impact analysis of minimum efficiency standards for refrigerators. According to a study of the National Association of Home Builders (NAHB 2007), the average life expectancy of refrigerators is 13 years.

[11] To identify the manufacturing year of the refrigerators replaced, we matched the DOE data with data from the California Energy Commission, which provides historical attribute data for refrigerators dating back to 1978. Our matching procedure can only recover detailed attribute information for a subset of refrigerators that were replaced under C4A (approximately 10,000) because not all states recorded the manufacturer appliance numbers of the replaced appliances. There were also some inconsistencies in the way the manufacturer numbers for replaced appliances were recorded in the C4A database. For clothes washers and dishwashers, we could not recover attribute information on the replaced appliances, because we do not have historical attribute data.

programs, which is \$0.06, on average (Arimura et al. 2012; Gillingham, Newell, and Palmer 2009; Auffhammer, Blumstein, and Fowlie 2008). In Table A.10 in the online Appendix, we also shows that C4A would have cost more than \$0.07 per kWh saved for refrigerators and dishwashers even if there were zero freeriding. Due to the much larger difference between ES and non-ES clothes washers' energy consumption, lower-freeriding proportions of 50 percent or less would have delivered cost-effectiveness on par with other utility-funded programs.

Would it have been possible to achieve better cost-effectiveness using alternative eligibility criteria? One limitation of ES-based rebates is that they provide an implicit subsidy for other attributes. To avoid these perverse incentives, we consider criteria solely based on electricity consumption. In other words, we construct a rebate that is not a function of the existing information (ENERGYSTAR) and regulatory (minimum efficiency standards) programs. For instance, we consider offering rebates only for products in the upper fifth, tenth, or twentieth percentiles of energy efficiency (i.e., lower fifth, tenth, or twentieth percentiles of expected electricity consumption). Of course, products that consume less electricity tend be smaller, and may have fewer features. Eligible products are thus most likely inferior in the non-energy dimension, which is at the source of welfare losses. The cost-effectiveness metric does not account for these losses. We find that using non-attribute based rebates improves the cost-effectiveness for refrigerators and dishwashers, only. However, the cost per unit energy saved is still high for these two appliance categories. For instance, the cost is above \$0.08 for each kWh saved if the proportion of freeriders is at least 70 percent.

In the online Appendix, we also present cost-effectiveness estimates that assume zero accelerated replacement. If consumers are purchasing new appliances and claiming rebates at the time that they planned to replace their existing appliances anyway, then there would be no benefit from prematurely scrapping an older, less-efficient appliance. As Table A.10 shows, the cost-effectiveness measures increase to as much as \$1.64 per kWh of expected energy saved.

C. *Comparison with Other Estimates*

The DOE contracted the consulting group D&R International to evaluate the impact of the C4A program. According to D&R, C4A had a large impact and led to important energy savings (D&R 2013).[12] Their estimate of the overall savings is 2 trillion BTU per year, and the major appliances contributed to savings of 815 billion of BTU per year.

To put these aggregate energy savings in perspective, D&R estimated average savings per rebate claim of 116 kWh/year, 257 kWh/year, and 57 kWh/year for refrigerators, clothes washers, and dishwashers, respectively.[13] We cannot reconcile these large energy savings with our estimated share of inframarginal consumers and short-term intertemporal substitution. We cannot even reconcile the refrigerator

[12] The report can be requested from the authors.

[13] Table A.9 reports their estimates for the three appliances that we study. D&R does not, however, provide details on their methods in the published report.

savings of 116 kWh/year with assumptions of 0 percent freeriding and 5-year accelerated replacement. The proportion of freeriders would have to be no more than 25 percent–30 percent for clothes washers and dishwashers, respectively, well below the 92 percent and 73 percent estimated free-riding rates in our analysis. These differences illustrate the importance of explicitly accounting for freeriding behavior and intertemporal substitution beyond the time horizon of program operation, in assessing the impact of energy efficiency subsidies on investment decisions and energy outcomes.

VII. Conclusions

In this paper, we investigate the impact of a nationwide energy efficient appliance rebate program, the State Energy Efficient Appliance Rebate Program, informally known as the Cash for Appliances (C4A) program. We estimate that about 70 percent of the consumers claiming a rebate would have bought an ES-rated appliance during the period of the state C4A programs in the absence of the rebates. An additional 15 percent to 20 percent of the rebate recipients changed the timing of the ES-rated appliance that they planned to buy anyway. We find economically meaningful evidence of upgrading, where consumers claimed rebates to purchase higher quality, but less energy-efficient models. We show that by making the rebates a function of ES certification, which is in turn a function of attribute-based energy efficiency standards, C4A acts as an implicit subsidy for larger appliances (as well as for other non-energy attributes). Income effects also appear to play a role in upgrading.

Such high rates of inframarginal consumers coupled with short-term intertemporal substitution and perverse upgrading translate into high costs per unit of electricity savings. With refrigerator rebate programs spending about \$1.10 for every expected kilowatt-hour saved, C4A cost an order of magnitude more than typical energy efficiency and conservation programs. Rebate programs for clothes washers and dishwashers, with cost-effectiveness ranging from \$0.21 to \$0.46 per kilowatt-hour saved, were more cost-effective than refrigerators, but still relatively expensive per unit of energy saved. The C4A programs transferred nearly \$300 million to households during and soon after the Great Recession. While it may have produced little improvement in the energy efficiency of appliance purchases, it played a modest role in the \$800+ billion economic stimulus package.

This empirical analysis of the Recovery Act's Cash for Appliances program has potentially important implications for future energy and climate change policies. The ENERGYSTAR program has been adopted by several countries (e.g., Canada and EU countries), and other countries have adopted similar energy labeling programs (e.g., India). These programs often serve as eligibility criteria for subsidy programs. In the United States, state governments and utilities frequently employ subsidies for ES-rated appliances and are likely to further increase their use in the future. In 2015, there were nearly 500 active utility rebate programs for ES-rated clothes washers, dishwashers, and refrigerators according to www.energystar.gov, and many of these programs have design attributes similar to the state C4A programs. In 2010, utility consumer-funded energy efficiency programs amounted to \$4.8 billion and such expenditures could double by 2025 (Barbose et al. 2013). Appliance rebates have traditionally been a significant component of such programs. Moreover, state governments are increasing their funding of energy efficiency programs as a result of revenues raised through the auctions of greenhouse gas cap-and-trade program allowances. At the federal level, appliance rebate programs may also play an important role in the implementation of the EPA's Clean Power Plan. In its regulatory impact analysis, the EPA notes that rebates for high-efficiency appliances could represent one approach for reducing power sector carbon dioxide emissions as called for under the plan (EPA 2014).

REFERENCES

Alberini, Anna, Will Gans, and Charles Towe. 2016. "Free Riding, Upsizing, and Energy Efficiency Incentives in Maryland Homes." *Energy Journal* 37 (1): 259–90.

Aldy, Joseph E. 2013. "Policy Monitor: A Preliminary Assessment of the American Recovery and Reinvestment Act's Clean Energy Package." *Review of Environmental Economics and Policy* 7 (1): 136–55.

Arimura, Toshi H., Shanjun Li, Richard G. Newell, and Karen Palmer. 2012. "Cost-effectiveness of electricity energy efficiency programs." *Energy Journal* 33 (2): 63–99.

Ashenfelter, Orley C., Daniel S. Hosken, and Matthew C. Weinberg. 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.

Auffhammer, Maximilian, Carl Blumstein, and Meredith Fowlie. 2008. "Demand-Side Management and Energy Efficiency Revisited." *Energy Journal* 29 (3): 91–104.

Bailey, Martha J. 2012. "Reexamining the Impact of Family Planning Programs on US fertility: Evidence from the War on Poverty and the Early Years of Title X." *American Economic Journal: Applied Economics* 4 (2): 62–97.

Barbose, Galen L., Charles A. Goldman, Ian M. Hoffman, and Megan Billingsley. 2013. "The Future of Utility Customer-Funded Energy Efficiency Programs in the United States: Projected Spending and Savings to 2025." Ernest Orlando Lawrence Berkeley National Laboratory Working Paper LBNL-5803E.

Bils, Mark, and Peter J. Klenow. 2001. "Quantifying Quality Growth." *American Economic Review* 94 (4): 1006–30.

Boomhower, Judson, and Lucas W. Davis. 2014. "A credible approach for measuring inframarginal participation in energy efficiency programs." *Journal of Public Economics* 113: 67–79.

Chodorow-Reich, Gabriel, Laura Feiveson, Zachary Liscow, and William Gui Woolston. 2012. "Does State Fiscal Relief During Recessions Increase Employment? Evidence from the American Recovery and Reinvestment Act." *American Economic Journal: Economic Policy* 4 (3): 118–45.

Datta, Souvik, and Sumeet Gulati. 2014. "Utility rebates for ENERGY STAR appliances: Are they effective?" *Journal of Environmental Economics and Management* 68 (3): 430–506.

de la Rue du Can, Stephane, Greg Leventis, Amol Phadke, and Anand Gopal. 2014. "Design of incentive programs for accelerating penetration of energy-efficient appliances." *Energy Policy* 72: 56–66.

D&R. 2013. "State energy appliance rebate program: Final report." Unpublished.

Environmental Protection Agency (EPA). 2014. *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants*. Environmental Protection Agency. Washington, DC, June.

Gillingham, Kenneth. 2013. "The Economics of Fuel Economy Standards versus Feebates." http://www.ourenergypolicy.org/wp-content/uploads/2013/07/Gillingham-CAFE-Standards-vs-Feebates-Apr-20131.pdf.

Gillingham, Kenneth, Richard G. Newell, and Karen Palmer. 2009. "Energy Efficiency Economics and Policy." *Annual Review of Resource Economics* 1 (1): 597–620.

Goolsbee, Austan. 1998. "Investment Tax Incentives, Prices, and the Supply of Capital Goods." *Quarterly Journal of Economics* 113 (1): 121–48.

Hoekstra, Mark, Steven L. Puller, and Jeremy West. 2014. "Cash for Corollas: When Stimulus Reduces Spending." National Bureau of Economic Research (NBER) Working Paper 20349.

Houde, Sébastien. 2014. "Bunching with the Stars: How Firms Respond to Environmental Certification." http://terpconnect.umd.edu/~shoude/EnergyStarFirmsHoude_May2014.pdf.

Houde, Sébastien, and Joseph E. Aldy. 2017. "Consumers' Response to State Energy Efficient Appliance Rebate Programs: Dataset." *American Economic Journal: Economic Policy*. https://doi.org/10.1257/pol.20140383.

House, Christopher L., and Matthew D. Shapiro. 2008. "Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation." *American Economic Review* 98 (3): 737–68.

Ito, Koichiro, and James M. Sallee. 2014. "The Economics of Attribute-Based Regulation: Theory and Evidence from Fuel-Economy Standards." National Bureau of Economic Research (NBER) Working Paper 20500.

Joskow, Paul L., and Donald B. Marron. 1992. "What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs." *Energy Journal* 13 (4): 41–74.

Li, Shanjun, Joshua Linn, and Elisheba Spiller. 2013. "Evaluating 'Cash-for-Clunkers': Program effects on auto sales and the environment." *Journal of Environmental Economics and Management* 65 (2): 175–93.

Mian, Atif, and Amir Sufi. 2012. "The Effects of Fiscal Stimulus: Evidence from the 2009 Cash for Clunkers Program." *Quarterly Journal of Economics* 127 (3): 1107–42.

National Association of Home Builders (NAHB). 2007. *Study of Life Expectancy of Home Components*. National Association of Home Builders and Bank of America Home Equity. Washington, DC, February.

Sallee, James M. 2011. "The Surprising Incidence of Tax Credits for the Toyota Prius." *American Economic Journal: Economic Policy* 3 (2): 189–219.

Spurlock, C. Anna. 2013. *Appliance Efficiency Standards and Price Discrimination*. Ernest Orlando Lawrence Berkeley National Laboratory. Berkeley, CA, May.

Wilson, Daniel J. 2012. "Fiscal Spending Jobs Multipliers: Evidence from the 2009 American Recovery and Reinvestment Act." *American Economic Journal: Economic Policy* 4 (3): 251–82.