The Economics of Household Energy Efficiency: Evidence from Mexico's Cash for Coolers Program

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Abstract

This paper applies an economic framework for evaluating household energy efficiency to a large-scale appliance replacement program in Mexico that has helped 1.5 million households replace their old refrigerators and air-conditioners with energy-efficient models. Using household-level electric billing records from the universe of 25+ million Mexican residential customers we find that refrigerator replacement reduces electricity consumption by 7%, about one-quarter of the *ex ante* engineering estimates used to sell the program. Moreover, we find that air conditioning replacement actually *increases* electricity consumption. Overall, we find that the program is an expensive way to reduce externalities from energy use, reducing electricity consumption at a program cost of $.30 per kilowatt hour and reducing carbon dioxide emissions at a program cost of $500 per ton. Our framework and results underscore the urgent need for careful modeling of household behavior in the evaluation of energy-efficiency programs.

Key Words: Energy-Efficiency, Rebound Effect, Cash for Clunkers
JEL: D12, H23, Q40, Q54

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1. Introduction

Energy consumption is forecast to increase dramatically worldwide over the next several decades, raising enormous concerns about energy prices, geopolitics, and greenhouse gas emissions. Much of the recent energy research has focused on transportation and the demand for gasoline (Knittel 2011; Allcott and Wozny, 2011; Mian and Sufi, 2012; Busse, Knittel and Zettelmeyer, forthcoming). However, an equally important but neglected area is residential energy consumption. This category makes up 14% of total energy use worldwide, and is expected to grow by 34% through 2035 with almost all of the growth coming from non-OECD countries.[1]

Meeting this increased demand represents a severe challenge from both an economic and environmental perspective. To curtail demand use and the associated greenhouse gas emissions, policymakers are increasingly turning to programs that subsidize the replacement of older energy-inefficient durables such as cars and refrigerators with newer more energy-efficient models. One reason may be that these energy-efficiency policies are more politically palatable than first-best "carbon tax" approaches. Supporters of energy-efficiency policies argue that they represent a "win-win", reducing externalities while also helping participants reduce energy expenditures.[2] These claims are difficult to evaluate, however, because there is a surprisingly small amount of direct evidence.

In this paper, we use a well-known conceptual framework to characterize the effect of energy-efficiency policies on energy use and the welfare consequences of such policies when there are external costs from use. The framework is based on the idea that the demand for energy is derived from demand for household services produced using durable goods. More energy-efficient durable goods have lower energy costs of producing those services and hence households will tend to use them more. The more price elastic the demand for service, the smaller the energy savings from durable replacement. And, if the price elasticity is large enough, then replacement can actually

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[1] U.S. DOE (2011a), Tables D1 and D3. Wolfram, Shelef, and Gertler (2012) argue that residential energy consumption may increase even faster.

[2] McKinsey and Company (2009a), for example, argues that energy-efficiency investments are a "vast, low-cost energy resource" that could reduce energy expenditures by billions of dollars per year.

increase the demand for energy. Moreover, subsidies may encourage consumers to replace older durables with durables that are not only more efficient, but also have larger capacities and more capabilities to produce services, and thereby further reducing the energy savings.

We apply this framework to evaluate the impact and cost-effectiveness of a large-scale national appliance replacement program in Mexico. Since 2009, "Cash for Coolers" (hereafter, "*C4C*") has helped 1.5 million households replace their old refrigerators and air conditioners. To participate in the program a household's old appliance must be at least 10 years old and the household must agree to purchase an energy-efficient appliance of the same type. These old appliances are permanently destroyed, making the program similar to "Cash for Clunkers" and other well-known vehicle retirement programs.

We find that refrigerator replacement reduces electricity consumption by an average of 11 kilowatt hours per month, a 7% decrease. This is considerably less than what was predicted *ex ante* by the World Bank and McKinsey based on engineering models that ignore behavioral responses.[3] The World Bank study, for example, predicted savings for refrigerators that were about four times larger than our estimates. While electricity savings from refrigerator replacement is smaller than was predicted, we find that air-conditioning replacement actually *increases* electricity consumption. The magnitude varies substantially across months, with near zero changes during the winter and 20+ kilowatt hour increases per month in the summer.

This paper helps address an urgent need for credible empirical work in this area. Allcott and Greenstone (2012) argues that, "much of the evidence on the energy cost savings from energy-efficiency comes from engineering analyses or observational studies that can suffer from a set of well-known biases."[4] The lack of large-scale analyses of energy-efficiency programs is surprising given the immense policy importance of these questions. Electric utilities in the United States, for example, spent $22 billion

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[3] See Johnson, et. al (2009) and McKinsey and Company (2009b).

[4] Allcott and Greenstone (2012) go on to say, "We believe that there is great potential for a new body of credible empirical work in this area, both because the questions are so important and because there are significant unexploited opportunities for randomized control trials and quasi-experimental designs that have advanced knowledge in other domains."

dollars on energy-efficiency programs between 1994 and 2010, leading to a reported total savings of more than 1 million gigawatt hours of electricity.[5] Every major piece of U.S. federal energy legislation since the Energy Policy and Conservation Act of 1975 has included a substantial energy-efficiency component. Most recently, the American Recovery and Reinvestment Act of 2009 provides $17 billion for energy-efficiency programs.[6]

Our study is one of the first studies of an energy-efficiency program in a low or middle-income country.[7] Many low and middle-income countries are now adopting energy-efficiency policies. For example, development of energy-efficient appliances is one of the major initiatives of the *Clean Energy Ministerial*, a partnership of 20+ major economies, aimed at promoting clean energy.[8] And China recently announced a new large-scale program that will provide subsidies for energy-efficient refrigerators and air-conditioners. In part, these policies reflect a widely held view that there is an abundant supply of low-cost, high-return investments in energy-efficiency, particularly in developing countries (Zhou, Levine, and Price, 2009; Johnson, et. al, 2009; McKinsey and Company, 2009b).

A key feature of our analysis is the use of high-quality microdata. For this analysis we were granted access to household-level electric billing records for the universe of 25+ million Mexican residential customers. The sheer number of households in our analysis allow us to estimate effects precisely even with highly non-parametric specifications. In contrast, the primary source of data used in previous research on energy-efficiency programs in the United States comes from self-reported measures of energy savings from utilities. Economists have long argued that these self-reported measures of energy savings are overstated (Joskow and Marron, 1992).

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[5] U.S. DOE (1994-2011). Expenditures reported in year 2010 dollars.

[6] See http://www1.eere.energy.gov/recovery/ for a breakdown of energy-efficiency related projects funded by the *American Recovery and Reinvestment Act*.

[7] The small existing literature on energy-efficiency is focused mostly on the United States. See, for example, Dubin, Miedema, and Chandran (1986), Metcalf and Hasset (1999) and Davis (2008). There is also a related literature which uses utility-level data to evaluate energy-efficiency programs, again mostly in the United States (Joskow and Marron, 1992; Loughran and Kulick, 2004; Auffhammer, Blumstein, and Fowlie, 2008; Arimura, Li, Newell, and Palmer, 2011). Much of what is known about energy-efficiency in developing countries comes from studies based on highly-aggregated data (see, e.g., Zhou, Levine, and Price, 2010).

[8] See *http://www.cleanenergyministerial.org/* and *http://superefficient.org/* for details.

The fact that our analysis is based on a large-scale national program gives our results an unusually high degree of intrinsic policy interest. Program evaluation, particularly with energy-efficiency policies, is typically based on small-scale interventions implemented in one particular location. In these settings a key question is external validity i.e. how well do parameter estimates generalize across sites. Utilities that choose to participate in these programs tend to be considerably different from the population of utilities, raising important issues of selection bias (Allcott and Mullainathan, 2011). With *C4C*, we have a program that was available in all Mexican states so our results are nationally-representative.

The format of the paper is as follows. Section 2 describes the conceptual framework. Section 3 provides background information about the electricity market in Mexico and the *C4C* program. Sections 4 and 5 describe the data and empirical strategy and present the main results. Section 6 evaluates cost-effectiveness, calculating the implied cost of the program per unit of energy savings. Section 7 offers concluding comments.

2. A Conceptual Framework

2.1 Household Production and Energy Efficiency

In this section, we lay out a conceptual framework for evaluating residential energy efficiency programs like *C4C*. The framework is based on the well-known idea that demand for energy is derived from demand for household services that are produced in the home according to a household production technology.[9] Durable goods play a central role, determining the parameters of the household production technology and thus the price of different household services.

Households are assumed to choose the durable good portfolio that yields the highest level of utility,

$$\max_{\{j \in 1,\dots,J\}} \left\{V(\theta_1, y - r_1), \dots, V\left(\theta_J, y - r_J\right)\right\}, \tag{1}$$

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[9] See, for example, Hausman (1979), Dubin and McFadden (1984) and Baker, Blundell and Micklewright (1989). Our description of the household production technology follows closely Davis (2008).

where V is a conditional indirect utility function, θ_j is a vector of characteristics for durable good portfolio j, and y is household income. Portfolios differ in terms of characteristics θ_j and rental price r_j. Durable good replacement programs like *C4C* affects portfolio choices by subsidizing the rental price r_j of particular durable good portfolios.

The decision of which portfolio to purchase is made taking into account that whatever portfolio is purchased; it will be operated at the optimal level of utilization,

$$V(\theta_j, y - r_j) = \max_{\{z_1, z_2\}} U(z_1, z_2)$$

$$z_1 = f(x \mid \theta_j)$$

$$px + z_2 = y - r_j.$$

This household production problem formalizes the relationship between market inputs and services produced within the home. Household utility is defined over household services z_1 and a composite good z_2 with a price normalized to one. The production function for z_1 is denoted f and depends on inputs x. While in general there could be an entire vector of inputs, in the simplest case there is a single input, energy. The parameters of the household production technology depend on θ_j, the characteristics of the household's durable goods. These characteristics could include, for example, the energy-efficiency of the household's refrigerator. Households evaluate expenditure on inputs based on the utility derived from z_1 and the disutility of foregone consumption of composite good z_2. The budget constraint depends on a vector of input prices p, household income y, and on r_j, the per-period rental cost net of any available subsidy.[10]

If the production technology exhibits constant returns and there is no joint production, then the marginal cost of producing household services z_1 does not depend on the level of production. This is a significant analytical improvement because the household's problem may be treated as a classic demand problem,

$$V(\theta_j, y - r_j) = \max_{\{z_1, z_2\}} U(z_1, z_2)$$

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[10] These models typically assume that there are no borrowing constraints so households can spread the capital costs of durable good investments over many years. Gertler, Shelef, Wolfram, and Fuchs (2011) consider analytically and empirically how borrowing constraints can affect residential energy demand.

$$\pi_j \, z_1 + z_2 = y - \, r_j$$

where $\pi_j = \pi(p, \theta_j)$ is the marginal cost of producing z_1 using durable good j and is a function of and input prices p and durable good characteristics θ_j. In this reformulation of the problem marginal cost plays the traditional role of a price and the problem can be solved as usual by equating the marginal rate of substitution with the price ratio.

The solution to the household's conditional utility-maximization problem is described by a demand function for household services (z_1), a demand function for the composite good (z_2), and a conditional demand function for energy,

$$x = x\left(\pi_j \, , y - \, r_j \mid \theta_j\right).$$

Conditional on the characteristics of the durable good (θ_j), this function describes how demand for energy depends on the marginal cost of producing z_1 and net income.

2.3 The Rebound Effect

Using this conditional demand function for energy we consider in this subsection what happens when a household replaces an "old" durable good with a "new" more energy-efficient model. The change in energy consumption can be expressed,

$$\Delta x = \; x(\pi_{new} \, , y - \, r_{new} \mid \theta_{new}) - x(\pi_{old} \, , y - \, r_{old} \mid \theta_{old}).$$

Ignoring income effects which are likely to be small, there are two primary mechanisms by which a change in energy-efficiency affects energy consumption. First, an increase in energy-efficiency decreases the amount of energy used *per unit* of household services. For a fixed level of demand for household services an increase in energy-efficiency results in a proportional decrease in energy consumption. Second, an increase in energy-efficiency decreases the price of household services z_1 produced with that durable good, $\pi_{new} < \pi_{old}$. Energy-efficient durable goods cost less to operate so households will use them more, consuming a higher level of household services.

Sometimes called the "rebound" effect, this idea that improvements in energy-efficiency lead to increased utilization goes back at least 150 years.[11] Most of what has been written on the topic, however, has been based on introspection rather than empirical evidence. Some have argued that this behavioral response is so large that high-efficiency durable goods increase energy consumption, implicitly claiming that utilization is very price elastic (Owen, 2010). Others have argued that utilization elasticities are considerably smaller (Schipper and Grubb, 2000). Our view is that the magnitude depends crucially on the particular end-use in question, depending on several different factors.

First, a key determinant of the price elasticity of utilization is the availability of substitutes. Demand for services with few substitutes is relatively inelastic. Refrigeration is a good example. A household can switch entirely to non-perishable food but this requires a drastic change in diet and an increase in total food expenditures. For other household services there are more available substitutes. Take air-conditioning, for example. In the production of thermal comfort there are many possible substitutes. A household can use an electric fan, use more or differently natural ventilation, shut curtains during the day, spend more time outdoors, wear different clothing, etc.

Second, for some household services there simply is not much of an intensive margin. Again consider refrigeration and air-conditioning as examples. Most households leave their refrigerators plugged in 24 hours a day so there is little scope in the short-run to adjust utilization in response to a change in energy-efficiency. In contrast a household can easily adjust the level of utilization of air-conditioning. Households can adjust the settings on an air-conditioning unit, or turn it on and off, trading off the cost of operation versus thermal comfort.

Third, the price elasticity depends on income. For example, above a certain income level, a household is going to choose to use its air conditioner to maintain the ideal level of thermal comfort at all hours of the day so the price elasticity of demand for thermal comfort is very low. At lower income levels, however, households choose to operate

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[11] This idea is usually attributed to Jevons (1865) who argued that advances in the energy-efficiency of steam engines contributed to a 10-fold increase in British coal consumption between 1830 and 1863. Economists have long argued that the price elasticity of utilization is important to take into account when evaluating the cost-effectiveness of energy-efficiency standards. See, for example, Hausman and Joskow (1982).

their air-conditioners only on particularly hot days, or during particular hours of the day. Improvements in energy-efficiency will lead these households to increase their utilization, potentially by a substantial amount, and so these households will exhibit a higher price elasticity of demand.

2.4 The Adoption Decision

With this understanding of the household's utilization decision, let us now return to the decision of which durable good portfolio to adopt as specified in (1) above. It is important to remember that consumers do not choose just between an old and new technology but rather faces a continuum of alternatives. We characterize this choice in Figure 1a with the unconditional demand function for household services. Movements along the demand curve for household services reflect changes along both the intensive and extensive margins. For example, a household can increase its consumption of air-conditioning either by using a particular air-conditioner more intensively, or by adopting a higher-capacity unit. Also, while a household has limited ability to get more services out of a particular refrigerator, it can increase the amount of food it keeps cold by buying a bigger refrigerator.

The choice of θ_j determines the marginal cost of services and thereby effectively where to locate along the demand curve. With the older, less energy-efficient durable good (θ_{old}), the marginal cost of household services is high and the household chooses to consume a relatively low level of household services, z_{old}. With the newer, more energy-efficient durable good (θ_{new}), marginal cost is lower and the household chooses to consume a higher level of household services, z_{new}. As indicated in gray, there is a private benefit from replacing an old durable with the new more efficient durable good. In choosing which durable good portfolio to adopt, the household compares this private benefit against the difference in rental price.

Durable goods are often differentiated not only by energy-efficiency, but also by other features. For example, air conditioners have become much quieter over time. Whereas changes in durable good energy-efficiency are movements along the demand curve, improved features shift the demand curve right as indicated in Figure 1b.

Households should be thought of as producing multiple services. For example, households care both about ambient temperature and about ambient noise. As technological innovation makes air-conditioners quieter, this increases household willingness-to-pay for cooling. Most discussions of the “rebound effect “fail to carefully distinguish between changes in marginal cost (i.e. movements along the demand curve) and increases in joint production (i.e. shifts in the demand curve). Passenger vehicles have become more energy-efficient over time, but also have become much more powerful, comfortable, safe, and easy to drive. And refrigerators now provide ice and cold water through the door in a more convenient manner than before.

2.5 Welfare

In this subsection we discuss the welfare implications of a subsidy program like *C4C*. The primary economic rationale for energy-efficiency programs is externalities. There are external costs of energy use that place a wedge between private and social cost. Although it would be more efficient to tax the externality directly, first-best approaches are not always politically feasible and it is valuable to consider the conditions under which a second-best policy like *C4C* would increase welfare.

As mentioned in the introduction, supporters of energy-efficiency policies argue that they represent a “win-win”, reducing externalities and helping participants reduce energy expenditures. However, from a welfare perspective this second “win” is really an efficiency loss. The funds used for these subsidies come from taxpayers, and their loss is as big or bigger than the gain experienced by the subsidy recipient. In any energy-efficiency program some households are completely inframarginal, i.e. they would have purchased the energy-efficiency durable good even without the subsidy. These households value each $1 in subsidy at exactly $1, and the subsidy should be viewed as a pure transfer from taxpayers to program participants.

When policymakers talk about energy-efficiency programs they have in mind, instead, the households who are truly marginal. These are households who without the subsidy would have stayed with their old, energy-efficient durable good, but are induced by the subsidy to adopt a more energy-efficient technology. The size of the welfare gain for these households is bounded above by the amount of the subsidy, and bounded below by zero. In particular, the welfare gain is zero for a household that, after receiving the subsidy, is exactly indifferent between the two technologies. These funds are coming from taxpayers so the program should again be viewed as a transfer; but in this case not a pure transfer. The program is shifting income away from taxpayers who value it 1:1, toward program recipients who value it at less than 1:1. Thus there is a welfare loss ranging from $0 to $1 per dollar of subsidy.

In addition to this welfare loss, collecting tax revenues distorts labor and other markets. Gruber (2010), for example, discusses 40% as a plausible value for the social cost of public funds so that raising $1 in public funds imposes $.40 in deadweight losses. This is above and beyond the welfare loss from recipient households valuing the subsidies less than 1:1. That is, even if households value these subsidies at 1:1, there still is welfare loss from the fact that households inefficiently change their behavior in response to income and other taxes. These distortions are particularly unfortunate when the funds go toward households who are inframarginal because welfare losses are being incurred to transfer income to households who would have purchased the energy-efficient durable good even in the absence of the subsidy.

These welfare losses must be compared to welfare gains from decreased externalities. The total change in externalities depends on: (i) the total number of households induced to adopt the energy-efficient durable good, and (ii) the reduction in externalities per adoption. With this first component, it is important to avoid counting inframarginal households. This is often challenging empirically because while one can observe the number of adoptions, it is difficult to construct a credible counterfactual to describe what would have occurred in the absence of the policy. Typically even more difficult to measure is this second component. Accordingly, this is where we focus most of our attention in the empirical analysis which follows.

In the empirical analysis that follows, we report measures of “cost-effectiveness”, such as the cost of reducing a kilowatt hour of electricity use. The numerator in these measures will be either the estimated total change in energy consumption or the estimated total change in externalities. And the denominator will be total expenditures on the program. Reporting cost-effectiveness facilitates comparisons to previous estimates in the literature. And although cost-effectiveness is not the same as welfare, the two are closely related. Suppose, for example, that one finds that $.40 in carbon dioxide abatement can be achieved per $1 of subsidy. Whether or not this is welfare-improving depends on how much the households value the subsidy per $1, and on the social cost of public funds. If households value the subsidy at its full dollar value and if the social cost of public funds is 40%, then the program is welfare neutral.

There may also be additional welfare costs from durable good replacement programs that are not incorporated in the cost-effectiveness measures, but that we will discuss where appropriate. Permanently destroying old durable goods means that they are not available to be sold in secondary markets. In some cases these older durable goods will be of limited economic value. In other cases, there is a substantial market for these used durable goods, and the buyers in these markets are made worse off. Finally, there are indirect costs from energy-efficiency programs from program design, advertising, administration, and enforcement that would be incorporated in a comprehensive cost-benefit analysis. Direct measures of these indirect costs are often not available but economists have long argued that they may be substantial (see, e.g., Joskow and Marron, 1992).

This discussion again highlights that durable good replacement programs are necessarily going to be less efficient than a tax on the externality. Whereas Pigouvian taxes work along both adoption and utilization margins, durable good subsidies change adoption behavior only, shifting households that are at the margin between the two technologies, but having no impact on the intensity with which these durable goods are used. And whereas a tax raises revenue that can be used to offset distortionary taxes, the subsidy imposes additional welfare costs because participating households value the subsidy less than 1:1 and because of the social cost of public funds. It is true that subsidies are more politically palatable, but this advantage must be weighed carefully against these substantial disadvantages with regard to efficiency, and there is no guarantee that a subsidy program is going to be welfare-improving.

3 Cash for Coolers

3.1 Context and Program Rationale

The Mexican Federal Electricity Commission (*Comisión Federal de Electricidad*, or "CFE") is the exclusive supplier of electricity within Mexico. CFE is responsible for almost all electricity generation in Mexico, as well as all electricity transmission and distribution. Over 98% of Mexican households have electricity. Electricity service is highly reliable, with total service interruptions per household averaging just over one hour per year (CFE 2011, Table 5.14).

Residential customers are billed every two months. If a customer fails to pay their bill eventually electricity service to the home is terminated until the complete balance has been paid. The standard residential tariff in Mexico is an increasing block rate with no monthly fixed fee and three tiers. Residential electricity consumption is subsidized by the Mexican Federal government. Prices on the first tier tend to be low by international standards. As of August 2011, customers on the first-tier (tariff 1), paid 0.73 Pesos (5.7 U.S. cents) per kilowatt hour. The second and third tiers are considerably more expensive, 1.21 Pesos (9.6 cents) and 2.56 Pesos (20.2 cents) per kilowatt hour, respectively. As a point of comparison, the average price paid by residential customers in the United States is 11.5 cents.[12] The Mexican Energy Ministry estimates that residential customers face a price that is, on average, about half the average cost of providing power.[13]

Electricity consumption per capita is low but increasing rapidly. Average per capita electricity consumption for Mexico is 1,900 kilowatt hours annually, compared to 13,600 for the United States.[14] Over the next several decades, electricity generation in Mexico is forecast to increase 3.2% per year, almost quadruple the rate forecast for the

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[12] U.S. DOE (2011b), Table 7.4 "Average Retail Price of Electricity to Ultimate Customers by End-Use Sector". This is for 2009, the most recent year for which data is available.

[13] SENER (2008), Tables 50 and 51, report that for 2007 the average residential price was 0.998, compared to an average supply cost of 2.189 (both in pesos per kilowatt hour). Using the average exchange rate during 2007 from Banco de Mexico (10.93 pesos per dollar), and the Consumer Price Index from the Bureau of Labor Statistics this is 9.6 cents and 21.1 cents, respectively, in year 2010 dollars. Part of this reflects line losses, particularly on the low voltage distribution lines used to deliver electricity. In personal correspondence CFE explained that these losses average approximately 23%, so to provide 100 kilowatt hours CFE must generate 130.

[14] Electricity consumption per capita comes from World Bank, *World Development Indicators* for 2008.

United States.[15] One of the major drivers of this increase in demand is the increase in residential appliance ownership, due to poverty reduction and economic growth. Figure 2 plots ownership rates for televisions, refrigerators, and vehicles by income level in Mexico. As incomes increase households first acquire televisions, then refrigerators and other appliances, and it is not until income reaches substantially higher levels that households acquire vehicles. This pattern is typical of developing countries (Gertler, Shelef, Wolfram and Fuchs, 2011).

Meeting this increased energy demand will require an immense investment in generation and transmission infrastructure. The Mexican Energy Ministry has calculated that $100 billion dollars will need to be invested in new electricity generation and transmission infrastructure between 2010 and 2025.[16] The *C4C* program is viewed by policymakers as one of the ways to potentially reduce these looming capital expenditures. Part of the broader goal of our analysis is to consider whether energy-efficiency programs like *C4C* could serve as a substitute for these capital-intensive investments.

The program was implemented, in part, because *ex ante* engineering analyses had predicted that appliance replacements would lead to substantial decreases in electricity consumption. In independent studies of available energy-related investments in Mexico the World Bank and McKinsey concluded that replacing residential refrigerators and air-conditioners would be extremely cost-effective.[17] In fact, both reports found a *negative* net cost for these investments. That is, these were found to be investments that would pay for themselves even without accounting for carbon dioxide emissions or other externalities. At the heart of these predictions are optimistic predictions about the amount of electricity saved per replacement. The World Bank report, for example, considers an intervention essentially identical to *C4C*, in which refrigerators 10 years or older are replaced with refrigerators meeting current standards. The World Bank predicted that these refrigerator replacements would save 482 kilowatt hours per year, with larger savings for very old refrigerators. We revisit these predictions below,

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[15] U.S. DOE (2011a), p. 91.

[16] See SENER "Prospectiva del Sector Eléctrico: 2010-2025", published 2010, p.22. Dollar amounts are reported in U.S. 2010 dollars using the average exchange rate for that year (12.645 pesos per dollar).

[17] See Johnson, et. al (2009), Figure 2 and McKinsey and Company (2009b), Exhibit 4.

contrasting them with the results from our empirical analysis.

This emphasis on refrigerators and air-conditioners makes sense given the important role that these appliances play in energy demand. This is true not only in Mexico but throughout the world. Refrigerators and other "white goods" play perhaps even a more important role than vehicles given that saturation levels are so much higher. Table 1 shows that in a large group of developing countries, almost 1/3rd of households have refrigerators while only 5% have vehicles. As incomes increase and families emerge from poverty, they first acquire refrigerators and other household appliances, and it is not until income reaches substantially higher levels that households acquire vehicles (Wolfram, Shelef, and Gertler, 2012).

3.2 Program Details

Launched in March 2009, the objective of the *C4C* program is to reduce electricity consumption and thereby reduce carbon dioxide emissions. Unlike *Cash for Clunkers*, the program has never been viewed as an economic stimulus program.[18] The program is administered by the Mexican Energy Ministry (*Secretaría de Energía*, or "SENER") which oversees the broader energy sector in Mexico and carries out medium and long-term market analyses.[19]

This is a national program. Subsidies are available for both refrigerators and air conditioners, but 90%+ of the replacements to date have been refrigerators. To participate in the program a household must have a refrigerator or air conditioner that is at least 10 years old and agree to purchase a new appliance of the same type. The old appliances are supposed to be working at the time of replacement. This is enforced by the participating retailer who takes away the old appliance at the same time the new

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[18] Dozens of similar programs have been recently implemented in the United States, albeit at a much smaller scale. Most U.S. programs emphasize rebates for new energy-efficient appliances with no requirement that the old appliance be permanently destroyed. U.S. Department of Energy Secretary Steven Chu has made residential appliances one of the major areas of emphasis, "Appliances consume a huge amount of our electricity, so there's enormous potential to both save energy and save families money every month." This statement was part of a press release on July 14, 2009 announcing $300 million in funding explicitly targeted for residential appliances. This funding was awarded to states and primarily took the form of rebate programs.

[19] The official name of the program is *Programa de Sustitución de Equipos Electrodomésticos para el Ahorro de Energía*. The program is popularly known as *Cambia tu Viejo*.

appliance is delivered. Households are eligible to replace only one appliance of each type and the new appliances must meet certain size requirements.[20] Participants must purchase new appliances that exceed Mexican energy-efficiency standards by at least 5%. Mexican energy-efficiency standards for refrigerators and air-conditioners are identical to U.S. standards.

The program provides both direct cash payments and subsidized financing. The direct cash payments come in two different amounts, approximately corresponding to \$140 and \$80 dollars. To qualify for the more generous subsidy a household needs to have a low level of mean electricity consumption. Households with medium levels of electricity consumption were eligible for the smaller subsidy, and households with high levels of electricity consumption were eligible for subsidized financing only. This structure was implemented out of distributional concerns in an attempt to target the program to lower-income households. Mean electricity consumption is calculated over the previous year. For refrigerator replacements mean consumption is calculated over non-summer months only. For air conditioners mean consumption is calculated over summer months.

Subsidized financing is subject to eligibility requirements that are similar to those in place for the direct cash payments. The financing comes in the form of a one-time credit that is paid back over a 4-year period. The loans are offered at a preferential interest rate that is below typical rates for consumer loans in Mexico. Households need not have a credit history in order to qualify for these loans, though if a household does have a credit history it can be disqualified for having a poor credit history. The maximum credit amount available to a participating household depends on the household's mean electricity consumption, with higher maximum amounts available to households with higher levels of consumption.

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[20] Refrigerators must be between 9 and 13 cubic feet, and can have a maximum size no more than 2 cubic feet larger than the refrigerator which is replaced. Air conditioners are subject to similar requirements, both for the size of the new units and for the maximum size difference between the new and old units. In addition to these eligibility requirements there are several others. The individual requesting the subsidy must have their name on the electricity bill, have a public registered ID number (CURP), be 18 years old or older, be in good standing with the electricity company (i.e. no balance), and not be an employee of the electricity company or other affiliated governmental body. For air-conditioners participants additionally must reside in relatively hot parts of the country, corresponding to electricity tariffs 1C, 1D, 1E, or 1F.

Households can accept the cash subsidy, the subsidized financing, or both. In practice, all households choose to accept the cash subsidy, but many households decide not to use the subsidized financing. In addition to these two incentives, most participants are eligible for an additional subsidy (approximately $30 dollars) that is used to pay for the transport and disposal of the old appliance. The retired appliances are transported to recycling facilities and disassembled.[21] Stores are reimbursed for the subsidy about one month after the file is completed, which includes verified receipt of the old appliance at one of the recycling facilities.[22]

3.3 Program Take-up

By February 2012, *C4C* had provided subsidies for 1.5 million refrigerator replacements. This is a large number of participants compared to most energy-efficiency programs. It is important, however, to compare this to the number of eligible households. At the beginning of the program there were approximately 23 million refrigerators owned nationwide, of which 10 million (43%) were more than 10 years old (Arroyo-Cabañas, et al., 2009). As of February 2012, therefore, about 15% of all eligible households had participated in the program.

Empirically it appears that *C4C* has had a substantial impact on refrigerator sales. During 2009, 2010, and 2011 there were 6.8 million refrigerators sold in Mexico.[23] Based on the available data from pre-*C4C* we would have predicted 5.4 million sales. This yields a difference of 1.4 million refrigerators, similar to the total number of refrigerators replaced through *C4C*. This back-of-the-envelope calculation is based on a linear

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[21] At these *Centros de Acopio y Destrucción* the appliances are disassembled according to environmental standards established by SENER. Facility operators are trained, in particular, in the safe disposal of CFCs, and a record is maintained of recovered refrigerants. Andrade (2010) provides a detailed description of the recycling facilities and their environmental performance to date.

[22] Given the structure of the market we suspect that the *incidence* of the subsidy is largely on households. Supply of appliances is highly-competitive in Mexico with 10+ companies involved in manufacturing refrigerators and air-conditioners, and a similar number of large national retailers. Multinational appliance companies like GE, LG, Samsung, and Daewoo have a significant presence in Mexico and the global manufacturing capacity to quickly adjust supply in response to changes in demand.

[23] This number comes from personal correspondence with the Mexican National Association of Electric Materials (*Cámara Nacional de Materiales Eléctricos, CANAME*). Based on their own internal analysis of national-level sales data, CANAME concludes that *C4C* has generated through March 2012 a total of 900,000 additional refrigerator sales and 160,000 additional sales of air-conditioners (both about 60% of total *C4C* replacements).

extrapolation of pre-2008 sales reported by Arroyo-Cabañas, et al. (2009) and does not control for macroeconomic conditions. If anything, however, one would have expected the recession post-2008 to decrease sales relative to the trend.

Some of the households who have participated in *C4C* should nevertheless be viewed as inframarginal, i.e. households who would have replaced their appliances even in the absence of the subsidy. Even in these cases, however, the program does have an impact on energy consumption. Mexico has well-functioning secondary markets for appliances and the saturation level for refrigerators and air-conditioners is well below 100%. Thus had they not been used in the program, many of these appliances would have otherwise been resold to other households.

Ancillary evidence from the Mexican Census implies that about half of refrigerator sales in Mexico are replacement purchases, while the other half are purchases by first-time buyers. Households in the Census are asked whether or not they own a refrigerator and other household appliances (see Table 2). In the Census between 2000 and 2005, the total number of households with refrigerators increased by 4.1 million. During this same period 7.3 million new refrigerators were sold.[24] In an economic model of scrappage, households replace durable goods when repair costs exceed the economic value of the good (Hahn, 1995). Older refrigerators use more electricity so operating costs are an important factor, on top of repair costs, for households deciding whether or not to replace an existing refrigerator.

These comparisons also suggest that there is only a modest amount of trade in used appliances between the United States and Mexico. Differences in income levels, repair costs, and other factors imply that there are gains to trade in used durable goods. Davis and Kahn (2010) document, for example, that since trade restrictions were eliminated in 2005, Mexico has imported three million used cars and trucks from the United States. Although data are not available for used refrigerators and air-conditioners, this is undoubtedly an important option for some Mexican households, particularly for poorer households who perhaps are acquiring one of these appliances

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[24] A similar exercise can be performed using the Mexican National Income and Expenditure Survey ("ENIGH"). In ENIGH between 2000 and 2008, the total number of households with refrigerators increased by 5.2 million, compared to 12.1 million sales of new refrigerators.

for the first time. However, the fact that sales volumes for new appliances in Mexico are large compared to changes in the stock suggests that the majority of Mexican demand is being satisfied by new appliances.

4 Data and Empirical Framework

4.1 Data Description

The central dataset used in the analysis is a two-year panel dataset of household-level electric billing records.[25] These data describe bimonthly electricity consumption and expenditure for the universe of Mexican residential customers from May 2009 through April 2011. Each record includes the customer account number, county and state of residence, climate zone, tariff type, and other information. For confidentiality reasons these data were provided without customer names. The complete set of billing records includes data from 26,278,397 households. We dropped 15,262 households (<0.001%) for whom the records are improperly formatted and 1,113 households for whom no state was indicated. We also drop 491,788 observations (1.9%) with zero reported usage in every month of the panel.

In Mexico residential electricity is billed every two months using overlapping billing cycles. We assign billing cycles to calendar months based on the month in which the cycle ends. We then normalize consumption to reflect monthly consumption by dividing by the number of months in the billing cycle. The average number of months per billing cycle is 1.98 months, with 93% of all cycles representing two months. An additional 5% of all cycles represent one month, with the remaining 2% representing 3+ months. These irregular billing periods arise for a variety of reasons. For example, some households in extremely rural areas have their meters read less than six times per year.

Equally important for the analysis is a second dataset which describes *C4C* participants. These data were provided by SENER and describe all participants in the

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[25] These data were provided to the University of California Energy Institute (UCEI) pursuant to the terms and restrictions of a Non-Disclosure Agreement signed May 3, 2011 with Mexican Federal Electricity Commission (CFE). As part of the agreement UCEI has agreed to share their results with CFE and to carefully consider any comments received. Of course to ensure objectivity, UCEI retains the exclusive right to determine how these comments are incorporated into their findings. Neither UCEI nor the authors have received any financial compensation from CFE.

program between March 2009 and June 2011, a total of 1,162,775 participants. We dropped 51,823 participants (4.5%) for whom no installation date for the new appliance was recorded. We merged the remaining data with the billing records using customer account numbers. We were able to match 86% percent of *C4C* participants with identical account numbers in the billing records. Each record in the program data includes the exact date in which the appliance was replaced, whether the appliance replaced was a refrigerator or an air-conditioner, the amount of direct cash subsidy and credit received by the participant, the reported age of the appliance that was replaced, and other program information. We drop 93 households (<.0001% of participants) who replaced more than one air-conditioner, leaving us with 957,080 total treatment households.

4.2 Empirical Strategy

This section describes the estimating equation used for our baseline estimates of the effect of refrigerator and air-conditioner replacement on household electricity consumption. The basic approach is difference-in-differences. In the preferred specification, impacts are measured by comparing electricity consumption before and after appliance replacement using a rich set of time effects that vary across locations. The sheer size of our dataset and immense number of treatment and control households allows us to estimate effects precisely while using highly non-parametric specifications.

Our empirical approach is described by the following regression equation,

$$y_{it} = \beta_1 1[New\ Refrigerator]_{it} + \beta_2 1[New\ Air\ Conditioner]_{it} + \gamma_{i,moy} + \omega_t + \varepsilon_{it}.$$

where the dependent variable y_{it} is electricity consumption by household i in month t measured in kilowatt hours. In the baseline specification we include all available observations from May 2009 through April 2011. Billing is bimonthly so for most households we have 12 observations. The covariates of interest are $1[New\ Refrigerator]_{it}$ and $1[New\ Air\ Conditioner]_{it}$, indicator variables equal to one for *C4C* participants after they have replaced their refrigerator or air-conditioner. Parameters β_1 and β_2 measure the mean change in electricity consumption associated with appliance replacement, corresponding to Δx in the conceptual framework.

Our preferred specifications include household by month-of-year fixed effects, $\gamma_{i,moy}$. That is, for each household we include 12 separate fixed effects, one for each calendar month (e.g, January, February, etc).[26] This controls not only for time-invariant household characteristics such as the number of household members and size of the home, but also household-specific seasonal variation in electricity demand. For example, some households have air-conditioning and some do not, so electricity demand varies differentially across the year for different households.

All estimates also include month-of-sample fixed effects ω_t. This controls for month-to-month differences in weather as well as for population-wide trends in electricity consumption. Many specifications include, instead, month-of-sample by county fixed effects ω_{ct}. This richer specification controls for county-specific variation in year-to-year weather, as well as differential population-wide trends across counties. Finally, the error term ε_{it} captures unobserved differences in consumption across months. In all results we cluster standard errors at the county level to allow for arbitrary serial correlation and correlation across households within counties.

4.3 Comparison Groups

We report regression estimates based on several different comparison groups. We first report results estimated using an equal-sized random sample of non-participating households. Next we report results estimated using a sample that includes participating households only. In this specification the participating households who have not yet replaced are the comparison group, and we can continue to include time effects in these regressions because households replaced appliances at different times. Finally, we report estimates from a set of regressions that are estimated using matching.

We consider two different matched samples. The first matched sample is based purely on location. We perform this matching using account numbers. Account numbers identify not only the state and county where each household lives, but also the specific

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[26] In the billing data we observe both the housing unit and the household. Consequently, we can observe when a new household moves into an existing housing unit. In the empirical analysis we treat each household / housing unit pair as a separate "household". With household by month-of-year fixed effects we are identifying the effects of *C4C* using only households who remain in a housing unit for at least one year.

route used by meter readers. For each *C4C* participant, we select as a comparison household the account corresponding to the closest consecutive non-participating housing unit. In many cases this is the household living immediately next door. These matched households are likely to be a better comparison group than non-participating households as a whole because of their close physical proximity to the treatment households. Weather is a major determinant of electricity consumption so this matching ensures, for example, that comparison households are experiencing approximately the same weather as the treatment households.

Our second matched sample is constructed based on both location and pre-treatment electricity consumption. We are somewhat limited in that we only have two years of data, and thus in many cases do not have a large number of pre-treatment observations for electricity consumption. To ensure the best possible matches given this limitation, we match on all available pre-treatment months. For example, if a household replaces in November 2010, we match using all observations between May 2009 and October 2010. When matching on both location and pre-treatment consumption level we adopt the following approach. We first select for each participating household the ten closest non-participating households. Then among these ten we select the non-participating household whose average monthly pre-treatment consumption is closest to that of the participating household. For a small number of households (<2%) we have zero months of pre-treatment consumption and for these households we match on location only.

Figures 3a and 3b plot electricity consumption by month of the year for households who replaced refrigerators and air-conditioners and for the three main comparison groups. Notice that the scale for the y-axis is not the same in both figures and that the overall level of consumption tends to be considerably higher among households who replaced their air-conditioners. Electricity consumption is seasonal for all groups, increasing substantially during summer months. For households who replaced their refrigerators, all three comparison groups follow patterns that are reasonably similar to participating households. For households who replaced air-conditioners, non-participants as a whole do not appear to be a particularly good comparison group, with electricity consumption levels that are much lower and less seasonal. The matched comparison groups perform much better, and in particular, the match based on both location and pre-treatment consumption. The pattern for this last comparison group is very similar on average to the treatment group.

These matched samples help address potential concerns that non-participating households, as a whole, may not be a good comparison group. Households are self-selecting into the *C4C* program, and thus are likely to be very different from non-participating households. Most importantly they may have fundamentally different tastes for durable goods, and thus different trajectories for electricity consumption. Although we do not observe durable good holdings explicitly, matching on pre-treatment electricity consumption is likely to be an extremely good proxy.[27] This is particularly true because we are matching also by location, and thus effectively holding fixed both income and weather. Nonetheless we are acutely aware that this is non-experimental data and thus pay great attention in the section which follows to possible differential trends in electricity consumption.

5 Main Results

5.1 Graphical Results

This subsection presents graphical results intended to motivate the regression analyses that follow. We begin in this section with refrigerators rather than air-conditioners because they make up 90% of all appliance replacements, and because refrigerators lend themselves well to an event study analysis. Whereas refrigerator electricity consumption is approximately constant across months of the year, air-conditioning usage has a strong seasonal pattern which is better examined in a regression context.

Figure 4 describes graphically the effect of refrigerator replacement on household electricity consumption. The x-axis is the time in months before and after refrigerator replacement, normalized so that the month prior to replacement is equal to zero. The figure plots estimated coefficients and 95th percentile confidence intervals corresponding

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[27] Reiss and White (2005), for example, shows that electricity consumption is determined to a large degree by durable good holdings.

to the effect of appliance replacement by month, controlling for household and county by month-of-sample fixed effects. In particular, we plot the estimates of α from the following regression,

$$y_{it} = \sum_{k=-12}^{12} \alpha_k 1[\tau_{it} = k]_{it} + \gamma_{i,moy} + \omega_{ct} + \varepsilon_{it}$$

where τ_{it} denotes the event month defined so that τ=0 for the exact month in which the refrigerator is delivered, $\tau = -12$ for twelve months before replacement, $\tau = 12$ for twelve months after replacement, and so on. The coefficients are measured relative to the excluded category ($\tau = -1$). Both sets of fixed effects play an important role here. Without the county by month-of-sample fixed effects (ω_{ct}), for example, the effect of replacement could be confounded with seasonal effects or slow-moving county-specific changes in residential electricity consumption. The sample used to estimate this regression includes the complete set of households who replaced their refrigerators and an equal number of non-participating households matched to the treatment households using location and pre-treatment consumption.

During the months leading up to replacement electricity consumption is almost perfectly flat, suggesting that the fixed effects are adequately controlling for seasonal effects and underlying trends. Beginning with replacement electricity consumption falls sharply by approximately 10 kilowatt hours per month. Consumption then continues to fall very gradually over the following year. We attribute the fact that the decrease appears to take a couple of months to the fact that the underlying billing cycles upon which this is based are bimonthly, and to a modest amount of measurement error in the replacement dates. Moreover, the gradual decline between months +2 and +12 likely reflects a modest differential time trend between the treatment and comparison households. In all periods the coefficients are estimated with enough precision to rule out small changes in consumption in either direction.

With Figure 5 we perform the exact same exercise but assigning event study indicators to the comparison group, rather than the treatment group. For this figure, we assigned hypothetical "replacement" dates equal to the replacement date of the participating household to which each comparison household is matched. The figure exhibits no change in consumption at time zero, providing evidence that the sharp change observed in the previous figure is indeed driven by changes to the treatment group. The figure exhibits a slight upward trend, consistent with modest differential time trends between the treatment and comparison groups. To address potential concerns about modest trends of this type, later in the paper we will report estimates which include parametric time trends. Overall, results are similar in those specifications indicating that our estimates are not being unduly affected.

5.2 Baseline Estimates

Table 3 presents baseline estimates. Least squares coefficients and standard errors are reported from five separate regressions. The regressions in columns (1)-(3) are estimated using the complete set of participating households and an equal-sized random sample of non-participating households. The specification in column (1) includes household by calendar month and month-of-sample fixed effects. In this specification, refrigerator replacement decreases electricity consumption by 12.5 kilowatt hours per month. This is similar in magnitude to the difference observed in the event study figure. Mean electricity consumption among households who replaced their refrigerators is about 150 kilowatt hours per month so this is about an 8% decrease. Whereas refrigerator replacement decreases electricity consumption, the estimates indicate that air-conditioning replacement *increases* consumption by about 6.5 kilowatt hours per month. Mean electricity consumption among households who replaced their air-conditioners is about 400 kilowatt hours per month, so this is a 2% increase.

Column (2) adds month-of-sample by county fixed effects to better control for differences in weather and other time-varying factors. The point estimate for refrigerator replacement decreases to -10.4 and the point estimate for air-conditioner replacement increases slightly. In columns (3) we expand the specification to include an additional regressor corresponding to an interaction between air-conditioning replacement and the six “summer” months (May-October). We would expect air-conditioning replacement to have little effect on electricity consumption during cool months, and most meaningfully impact electricity consumption during warm months. The coefficient estimates appear to bear this out. While new air-conditioners appear to have little impact during winter months, the estimates indicate an increase in summer electricity consumption of 13.9 kilowatt hours per month.

Columns (4) and (5) present results from specifications in which we drop the comparison group entirely and estimate regressions using only participating households. These regressions continue to include month-of-sample by county fixed effects -- identified by exploiting differential *timing* of replacement across households. The estimates in column (4) change little compared to the previous columns, suggesting that what matters most in these regressions is the within-household comparison. Column (5), in addition, drops the month during which replacement occurred and results are again similar.

Each column in Table 3 represents a single regression in which we estimate effects for both refrigerators and air-conditioners. Estimates are essentially identical when we, alternatively, estimate these effects with separate regressions in each case keeping only households who replaced a certain type of appliance and the comparison households to which those households are matched. This is reassuring because it suggests that the time effects are adequately controlling for seasonal effects and underlying trends even though households who replaced air-conditioners have considerably higher baseline consumption levels. This also points to the importance of including household by calendar month fixed effects. Once these fixed effects are included, the R^2 in the regression is quite high and estimates are relatively stable across specifications.

5.3 Additional Specifications

Table 4 reports estimates based on matching. The estimating equations and sample of participating households are identical to Table 3, columns (1)-(3). But instead of a random sample of non-participants, these results are based on matched comparison groups. Overall, the results are very similar to Table 3. When matching on location and pre-treatment consumption, the point estimates for the effect of refrigerator replacement are somewhat smaller, ranging from -9.3 to -9.5 kilowatt hours per month. For air-conditioner replacement we continue to see a distinct seasonal pattern, with near-zero changes in electricity consumption in the winter, and an average increase of 15.3 kilowatt hours per month in the summer.

Figures 6A and 6B plot the effect of appliance replacement by month of year. To create these graphs we estimate the regression equation in Table 4, column (5) using 12 separate regressions, one for each calendar month. In each regression we keep only observations from a single calendar month. For example, for "May" we keep only electricity consumption that was billed in May 2009 or May 2010. Thus the estimated coefficient reflects the changes in electricity consumption from May to May, identified using households who replaced their appliances during any of the months between. For refrigerators the estimates are similar across calendar months, providing no evidence that the reduction in electricity consumption differs between hot and cold months. This is perhaps a mild surprise because engineering studies have found that ambient temperature is an important driver of refrigerator electricity consumption. It may be, however, that these thermal effects are too small to matter.

In contrast, the air-conditioner estimates follow a distinct seasonal pattern. Consistent with the regression estimates, the effect of air-conditioner replacement on electricity consumption is close to zero during winter months, but then large and positive during summer months. The largest coefficient corresponds to September. Because the billing data is bimonthly, this reflects change in consumption during August and September, two of the warmest months in Mexico.[28] As expected, utilization appears to matter importantly for air-conditioning. During cooler months thermal comfort is already high so households use their air-conditioners little or not at all. The value of air-conditioning is highest during hot months, and the evidence is consistent with an increase in consumption during these months.

These results rely on the comparison group being a reasonable counterfactual for

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[28] There are two months, May and June, in which the estimates are negative and statistically significant. With bimonthly billing, these coefficients reflect changes in consumption during April, May, and June. As described in Section 2, the change in electricity consumption reflects both the energy used per unit of cooling and the amount of cooling that is consumed. These negative coefficients in May and June are consistent with a relatively small increase in cooling during spring months. There is also presumably a relatively small increase in cooling during winter months (e.g. January and February) but also a very low base level of cooling consumption, consistent with our near-zero estimates.

what would have happened to participating households had they not replaced their appliances. We find it reassuring that results are similar across comparison groups, and similar even when no comparison group is used at all in Table 3, columns (4) and (5). Moreover, the sharp drop observed in electricity consumption among participating households in Figure 4, together with no sharp change in the comparison group, lends support to the interpretation of these changes as being *caused* by the program. Nonetheless, one could continue to be concerned that differential trends could be biasing our estimates. Our estimates assume that the change in electricity consumption in the comparison group is an unbiased estimate of the counterfactual. This is not testable. However, we can test whether the changes over time in the treatment group are the same as those in the comparison group in the pre-intervention period.

Table 5 reports tests of parallel trends versus our three different comparison groups. We estimate regressions identical to Table 3 (column 2) and Table 4 (columns 2 and 5), but include, in addition, a pre-treatment time trend for the treatment group. Across columns the estimated coefficient on this time trend is statistically significant, but small in magnitude. The time trend is measured in months, so in all three specifications the estimated coefficient on the time trend implies a change of less than 4 kilowatt hours per 12 months. This is small compared to mean consumption. A common correction for this modest pre-treatment trend is to include a parametric time trend for program participants following Heckman and Hotz (1989). Table 6 reports results including time trends. In these results, the comparison group is non-participants matched on location and pre-treatment consumption. The coefficient on refrigerator replacement increases modestly from -9.3 to -11.2 once a time trend has been included.

5.4 Heterogeneous Effects

Table 7 presents estimates for different subsets of participants. The table reports estimates and standard errors from six separate regressions. All regressions include household by calendar month and county by month-of-sample fixed effects. Panel (A) describes how the effect of appliance replacement varies by the mean household income in the county (from the 2010 Mexican Census). For refrigerators, the estimates are negative and statistically significant for all three income terciles with the largest decreases observed in the highest-income counties. It would appear that refrigerator replacement is most cost-effective among high-income households, perhaps reflecting that these households had larger refrigerators in the pre-period. For air-conditioners, the estimates are positive and statistically significant for all three income terciles. The point estimates increase with income levels, but are not statistically different from one another.

Panel (B) presents estimates separately by the year of replacement. The program was launched in 2009 and we have in our analysis replacements made during each of the first three years. Point estimates tend to increase across years. Refrigerators replaced during 2011, for example, tended to decrease electricity consumption by less than refrigerators replaced during 2009 and 2010. One might expect to see this if households who participate early in the program have the most to gain. For example, households with very old or very inefficient appliances would have likely wanted to participate in *C4C* as soon as possible. As time goes on, however, an increasing proportion of the participating households are those with appliances that are *exactly* 10 years old. These newly eligible households tend to have less to gain on average from replacement, and the estimates appear to bear this out.

5.5 Comparing Our Results to Ex Ante Predictions

The *ex ante* analyses predicted considerably larger savings from appliance replacement. The World Bank study, for example, calculated that replacing 10+ year old residential refrigerators in Mexico would save 481 kilowatt hours per year, with replacements of older refrigerators saving 700 kilowatt hours per year.[29] The same study calculates that replacement of residential air conditioners would save 1,200 kilowatt hours per year. Our estimates imply considerably smaller savings. Annual savings from refrigerator replacement are 134 kilowatt hours per year, about one-quarter of the

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[29] See Johnson, et. al (2009), Appendix C "Intervention Assumptions" pages 123-124 (air conditioners) and page 125 (refrigerators). Another point of comparison is Arroyo-Cabañas, et al. (2009) which predicted that replacing pre-2001 Mexican refrigerators would reduce electricity consumption by an average of 315 kilowatt hours per year.

savings predicted by the World Bank.[30] And for air-conditioning, we are finding that after replacement electricity consumption *increases* by 92 kilowatt hours per year.

One important explanation for the differences is that the *ex ante* analyses did not account for changes in appliance utilization. Although changes in utilization are likely to be modest or even non-existent for refrigerators, it makes sense that there would be a considerable change in utilization for air conditioning. In addition, it seems likely that some of the refrigerators and air-conditioners were not working at the point of replacement. Appliances were supposed to be in working order to be eligible for the program, but enforcement was performed by the participating retailer and was likely less than 100%. And even for appliances that were "working", there were likely some that were not working well, perhaps because they needed new refrigerant or other forms of maintenance.[31]

Another important factor is that appliance sizes have increased over time. Both refrigerators and air-conditioners were supposed to meet specific size requirements. New refrigerators were supposed to be between 9 and 13 cubic feet, and have a maximum size no more than 2 cubic feet larger than the refrigerator which is replaced.[32] Similar requirements were imposed for air conditioners. Again, however, it is likely that enforcement was less than 100%. Even modest increases in size would meaningfully offset the potential efficiency gains. For example, each additional cubic foot of refrigerator capacity adds about 10 kilowatt hours of electricity consumption per year.[33]

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[30] There is some precedent in energy-efficiency studies for finding that realized energy savings are smaller than *ex ante* engineering estimates. See, for example, Dubin, Miedema, and Chandran (1986) and Metcalf and Hassett (1999).

[31] Here there is a distinction between *C4C* and most vehicle retirement programs. "Cash for Clunkers", for example, required vehicles to have been registered for at least 12 months prior to being traded. There is no equivalent registration system for appliances making it more likely that a program brings in appliances that are not actually being used.

[32] Many of the refrigerators that were for sale during this period were larger than 13 cubic feet. In a July 2009 report, the Mexican Consumer Protection Office tested 27 refrigerators for sale in Mexico (PROFECO, 2009). Much like a typical report from *Consumer Reports*, models were evaluated on the basis of various characteristics. The average size among refrigerators that were tested was 13.5 cubic feet, and 17 out of 27 were larger than 13 cubic feet.

[33] Current energy-efficiency standards in the United States and Mexico specify that refrigerators with top-mounted freezers and automatic defrost without through-the-door ice have a maximum annual electricity use of $9.80AV+276.0$ where AV is the total adjusted volume in cubic feet. Under *C4C* new refrigerators were supposed to be between 9 and 13 cubic feet, implying a range of minimum consumption from 364 to 403 kilowatt hours per year, with each cubic foot adding 9.8 kilowatt hours per year.

Appliances have grown larger but also added additional features. Most new refrigerators have ice-makers, and many also have side-by-side doors and through-the-door ice and water. These features are valued by households but they are also energy-intensive. For example, through-the-door ice increases electricity consumption by about 80 kilowatt hours per year.[34] Air-conditioners have become quieter, and added features like lower cycle speeds (for operating a night), thermostats, and remote control operation. These features make air-conditioners easier and more convenient to use, likely leading to increased utilization.

Moreover, there is no evidence that the program was effective at targeting households with very old appliances. Program rules required appliances to be at least 10 years old and a disproportionate fraction of old appliances were reported to just barely meet this requirement. The average reported age of the refrigerators that were replaced is 13.2 years. Almost 70% were 10-14 years old, 20% were 15-19, and only 10% were 20 years or older. The average reported age for air-conditioners is 10.9 years and only 5% were reported to be more than 15 years old. There is likely to be significant measurement error in these self-reported ages, but this apparent lack of success at targeting very old appliances is important because energy-efficiency has improved steadily over time (see Figure 7). One possible explanation for the apparent lack of success at targeting very old appliances is the eligibility criteria. As was mentioned earlier, the most generous subsidies were available only for households with a low level of mean electricity consumption. This means that, ironically, households with very inefficient appliances tend to be ineligible for the most generous subsidies. Another explanation is income. Low-income households tend to have older appliances, and also may be less likely to participate in the program due to borrowing constraints or other factors.

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[34] Current energy-efficiency standards in the United States and Mexico provide separate requirements for refrigerators with and without through-the-door ice. Refrigerators without through-the-door ice have a maximum energy use of $9.80AV+276.0$ where AV is the total adjusted volume in cubic feet. The equivalent formula for refrigerators with through-the-door ice is $10.20AV+356.0$.

6 Cost-Effectiveness

6.1 Baseline Estimates

Table 8, Panel (A) reports the mean annual impacts implied by our estimates. Refrigerator replacement reduces electricity consumption by 134 kilowatt hours annually, while air-conditioner replacement increases electricity consumption by 92 kilowatt hours per year. At average residential electricity prices, refrigerator replacement saves households $13 annually, while air-conditioner replacement costs households an additional $9 annually.[35]

Panel (B) describes the total impact of *C4C* between May 2009 and April 2011. During this period there were about 850,000 refrigerator replacements and about 100,000 air-conditioner replacements. Our estimates imply that total reduction in electricity consumption associated with the program is about 100 gigawatt hours annually. As a point of comparison, residential sales nationwide in Mexico totaled 49,000 gigawatt hours in 2009.[36] At average residential electricity prices this implies total savings of $10 million annually. This panel also reports estimates of the total change in carbon dioxide emissions. One of the central goals of *C4C* is to reduce carbon dioxide emissions so these estimates are an important measure of the effectiveness of the program. Multiplying the change in electricity consumption by the average carbon intensity of electricity generation in Mexico yields the total decrease in carbon dioxide emissions.[37] The total decrease in carbon dioxide emissions implied by our estimates is about 60,000 tons of carbon dioxide annually.[38] Using a conservative estimate for the social cost of carbon

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[35] These estimates were calculated based on the estimates in Table 4, column (5). To calculate household expenditure we used 9.6 cents per kilowatt hour, the average price of electricity for Mexican residential customers.

[36] Secretaría de Energía, "Prospectiva del Sector Eléctrico 2010-2025," released 2010, Table 12, "Ventas Internas Sectoriales de Energía Eléctrica, 1999-2009."

[37] According to Mexico Secretaría de Energía, ``Balance Nacional de Energía'', 2010, pages 53-54, electricity generation in Mexico in 2009 produced 113.4 million tons of carbon dioxide. According to Mexico Instituto Nacional de Estadística y Geografía, "El Sector Energético en Mexico 2009", Table 2.4.1, total electricity generation in 2009 was 193 billion kilowatt hours. Thus each megawatt hour (1000 kilowatt hours) of electricity generation implies an average of (113.4) / (193) = .59 tons of carbon dioxide emissions. Johnson, et. al (2009) report for Mexico in 2008 a somewhat lower emissions factor (.54).

[38] These calculations capture the energy consumed in refrigerator operation but not from the energy consumed in other parts of the refrigerator "life-cycle". Taking into account materials production and processing, assembly, transportation, dismantling, recycling, shredding, and recovery of refrigerant, Kim,

dioxide ($20 per ton) this implies an additional $1.2 million in benefits annually.[39]

Panel (C) reports baseline estimates of cost-effectiveness. Based on the total number of participants and the subsidies that they received we calculate that direct program costs were $130 million for refrigerators, and $13 million for air-conditioners. This includes the cash subsidies received by households, but not costs incurred in program design, administration, advertising, or other indirect costs. Dividing by the estimated change in electricity consumption provides a measure of the direct program cost per kilowatt hour reduction. The relevant change here is the total discounted *lifetime* change in electricity consumption. For this calculation we adopt a 5% annual discount rate and assume that the program accelerated appliance replacement by 5 years. Under these assumptions the program cost per kilowatt hour is $.25 for refrigerators and $.30 overall. We do not report program cost per kilowatt hour separately for air-conditioners because the program led to an *increase* rather than a decrease in consumption. The program cost per ton of carbon dioxide emissions can be calculated similarly. For both refrigerators-only and for the entire program this exceeds $400 per ton.

These estimates of cost-effectiveness change predictably under alternative assumptions. The choice of a 5% discount rate is fairly standard in the literature (see, e.g., Arimura, Li, Newell, and Palmer 2011). With a 0% discount rate the program cost per cost per kilowatt hour is $0.27 compared to $0.30, and the program cost per ton of carbon dioxide is $456 compared to $502. The measures of cost-effectiveness are more sensitive to the assumption about how many years over which to calculate lifetime benefits. We have assumed that the program accelerates appliance replacement by 5 years but it seems likely that many of these participants were inframarginal, in which case the program does not accelerate replacement at all and 5 years is too generous. On the other hand, even for households who would have replaced their appliances anyway, the program prevents appliances from being resold to other households who might have

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Keoleian, and Horie (2006) find that energy usage during operation accounts for 90% of total life-cycle energy use.

[39] Greenstone, Kopits, and Wolverton (2011) presents a range of values for the social cost of carbon dioxide according to different discount rates and for different time periods that is intended to capture changes in net agricultural productivity, human health, property damages from increased flood risk, and other factors. In Table 4 with a 3% discount rate (their "central value") for 2010 they find a social cost of carbon dioxide of $21.40 (in 2007 dollars) per metric ton of carbon dioxide. In 2010 dollars this is approximately $22.

continued to use them for many years. If one assumes that the program accelerated appliance retirement program by 10 years, then the program cost per kilowatt hour is $0.17 compared to $0.30, and the program cost per ton of carbon dioxide is $281 compared to $502.

Some have argued that *C4C* would have been much more cost-effective if participants had been required to purchase more energy-efficient appliances. Program rules required participants to purchase refrigerators and air-conditioners that exceeded the minimum energy-efficiency standards by 5%. These standards date back to 2002, and the market for both refrigerators and air-conditioners has moved considerably past this. The United States, for example, has adopted new energy-efficiency standards for refrigerators that will take effect in 2014 that are about 25% more energy-efficient than current standards. A typical refrigerator meeting these more stringent standards uses 63 fewer kilowatt hours annually.[40] Had the refrigerator replacements saved 63 more kilowatt hours per year, the program cost per kilowatt hour (for refrigerators) would have been $0.20 compared to $0.30, and the program cost per ton of carbon dioxide (for refrigerators) would have been $333 compared to $502.

6.2 Discussion and Limitations

These estimates of cost-effectiveness are high compared to most estimates in the literature. For example, electric utilities in the United States reported in 2010 spending $2.9 billion in energy-efficiency programs leading to 87 terawatt hours of energy savings, implying an average direct program cost per kilowatt hour of 3.3 cents.[41] Economists have long argued that these self-reported measures likely overstate the cost-effectiveness of these programs (Joskow and Marron, 1992). Nonetheless, it is striking that our estimate for *C4C* is about 10 times larger.

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[40] Current energy-efficiency standards in the United States and Mexico specify that refrigerators with top-mounted freezers and automatic defrost without through-the-door ice have a maximum annual electricity use of $9.80AV+276.0$ where AV is the total adjusted volume in cubic feet. The new U.S. standard for this refrigerator type adopts a formula $8.07AV+233.7$ so a 12 cubic foot refrigerator uses 63 fewer kilowatt hours per year.

[41] U.S. DOE (2011b), Tables 9.6 and 9.7. As another point of comparison, Allcott (2011) reports a program cost per kilowatt hour for peer-comparison reports from OPOWER ranging from 2-5 cents.

With regard to carbon dioxide abatement an important point of comparison is *Cash for Clunkers*.[42] Knittel (2009) finds that the direct program cost for *Cash for Clunkers* exceeded $450 per ton. Our estimates for *C4C* are in the same ballpark. The high cost per ton in both cases reflects the fact that the carbon dioxide savings per replacement is relatively small and realized over relatively few years. Knittel (2009) assumes in the baseline estimates that *Cash for Clunkers* accelerated vehicle retirement by four years. Recent work by Mian and Sufi (2012) finds that the effect of the program on auto purchases was almost completely reversed by as few as 10 months after the program ended. If indeed the program accelerated retirement by so little, then the implied cost per ton of carbon abatement for *Cash for Clunkers* would be even larger.

As discussed in Section 2.5, cost-effectiveness is not the same as welfare though the two are closely related. The best case scenario from a welfare perspective is that these subsidies increase the welfare of participants by $1 for each $1 in subsidy, in which case the subsidy is a pure transfer. Even under this overly optimistic assumption, however, *C4C* appears to be an expensive way to reduce externalities. Spending $140 million for $1.2 million worth of carbon dioxide abatement only makes sense if one believes that the social cost of public funds is *extremely* low, i.e. less than 1%. Using a social cost of public funds of 40%, for example, would mean that raising $140 million would impose $56 million in welfare loss.

And, it is again worth pointing out that there are a couple of potentially important economic costs that are not reflected in these measures of cost-effectiveness. A comprehensive welfare analysis would need to take into account the costs borne by buyers in the secondary market for appliances. These households are, because of the program, now without access to the 1.5 million old refrigerators and air-conditioners that have been destroyed. These older appliances have real economic value, particularly in a country like Mexico where appliance saturation is less than 100%. And these measures of cost-effectiveness do not include the *indirect* costs from the program such as expenditures incurred in program design, administration, advertising, and enforcement.

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[42] An important distinction between *C4C* and *Cash for Clunkers* programs is that *C4C* was never envisioned as a stimulus program whereas with *Cash for Clunkers* one of the central objectives of the program from the beginning was to stimulate aggregate demand (Mian and Sufi, 2012).

7. Conclusion

Meeting the increase in energy demand over the next several decades will be an immense challenge. And it seems unlikely in the short term that there will be the political will to implement Pigouvian-style taxes on the externalities associated with the production and consumption of energy. Thus it is perhaps not surprising that policymakers are increasingly turning to energy-efficiency programs. In theory, these programs could represent a "win-win", reducing energy expenditures while also decreasing greenhouse gas emissions and other externalities. In countries where energy prices are subsidized, there is even a potential third "win" as governments reduce the amount they spend on subsidies. Moreover, among available energy-efficiency programs, an appliance replacement subsidy like *C4C* would appear to have a great deal of potential. Residential appliances have experienced dramatic gains in energy efficiency, so there would seem to be scope for these programs to substantially decrease energy consumption. And many of these durables have low baseline replacement rates, so it seems reasonable to believe that a subsidy could substantially accelerate their turnover.

Thus it is hard to not be somewhat disappointed by the estimated savings from *C4C*. We found that households who replace their refrigerators with energy-efficient models indeed decrease their energy consumption, but by an amount considerably smaller than was predicted by *ex ante* engineering analyses. Even larger decreases were predicted for air-conditioners, but we find that households who replace their air-conditioners actually end up *increasing* their energy consumption. Overall, we find that the program is an expensive way to reduce energy use, reducing electricity consumption at a program cost of about $.30 per kilowatt hour, and reducing carbon dioxide emissions at a program cost of about $500 per ton.

These results underscore the urgent need for careful modeling of household behavior in the evaluation of energy-efficiency programs. A central feature in our household production framework, and a key theme throughout the study, has been the importance of accounting for changes in utilization. Households receive utility from using these appliances, and they can and should increase utilization in response to increases in energy efficiency. This "rebound" is a good thing – it means that households are increasing their utility. It does, however, complicate the design of energy-efficiency policy and *ceteris paribus*, in pursuing environmental goals it will make sense for policymakers to target appliances for which demand for utilization is inelastic.

Our results also point to several additional lessons for the design and evaluation of energy-efficiency programs. Over time cars, appliances, and houses have become more energy efficient, but also bigger and better. These size and quality increases are another form of the demand for increased utilization, and it makes sense to take them into account when designing policy. There is also a tendency for energy-efficiency programs to lose effectiveness over time. While initially a program tends to attract participants with the most to gain, as time goes on the pool will be made up increasingly by participants who just barely meet the eligibility requirements. Finally, despite attempts by administrators to build enforcement mechanisms into program design, it is difficult to strictly enforce eligibility requirements. While one can envision third-party enforcement mechanisms, this adds costs to the program.

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FIGURE 1a
The Market for Household Services

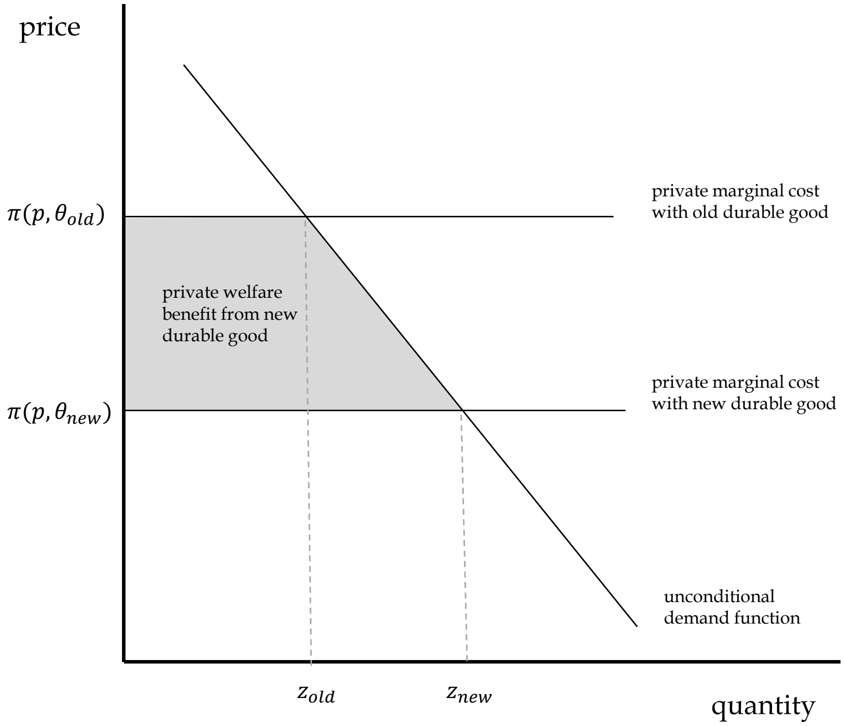


FIGURE 1b
An Increase in Joint Production

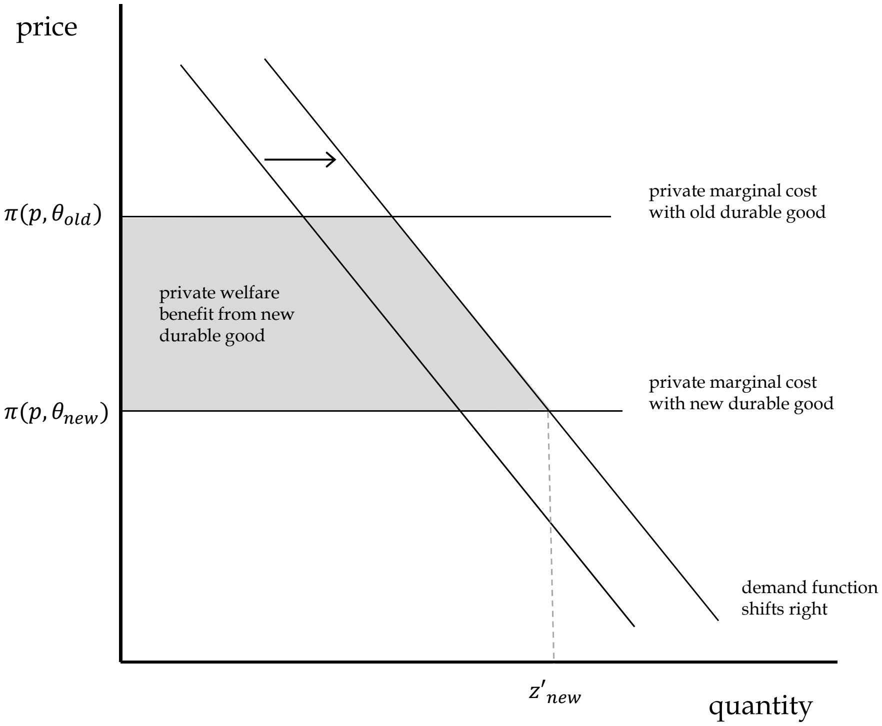


FIGURE 2
Durable Good Ownership Rates by Income Level in Mexico

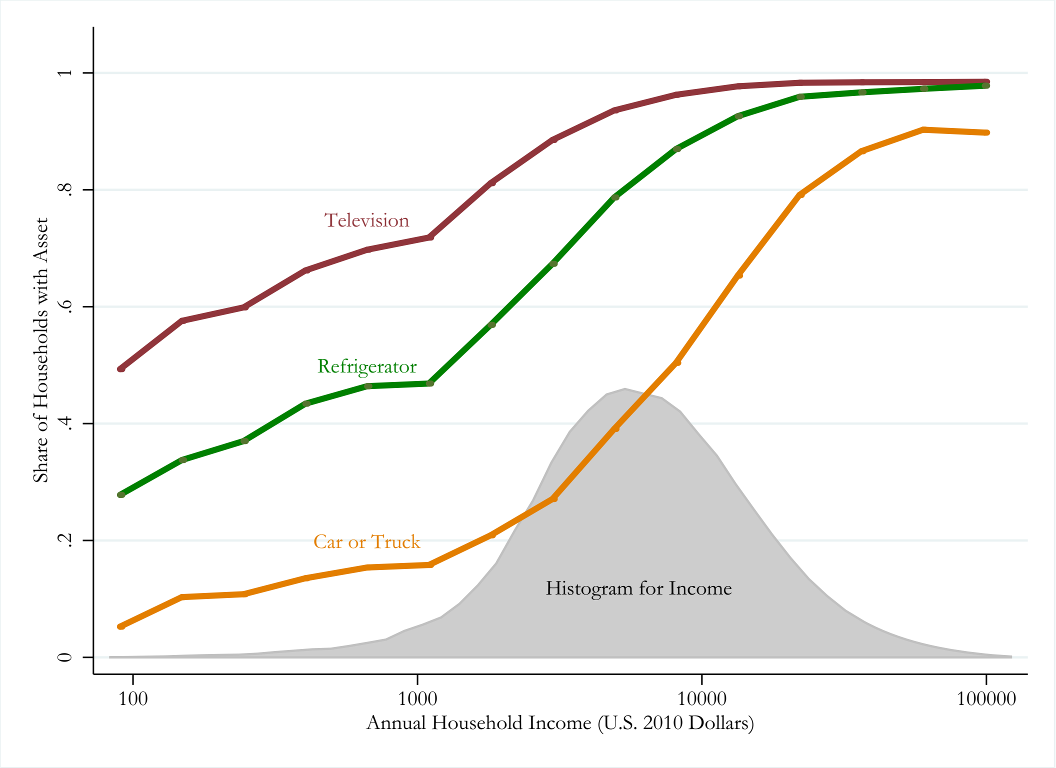


FIGURE 3a

Comparing Participants to Non-Participants: Refrigerators

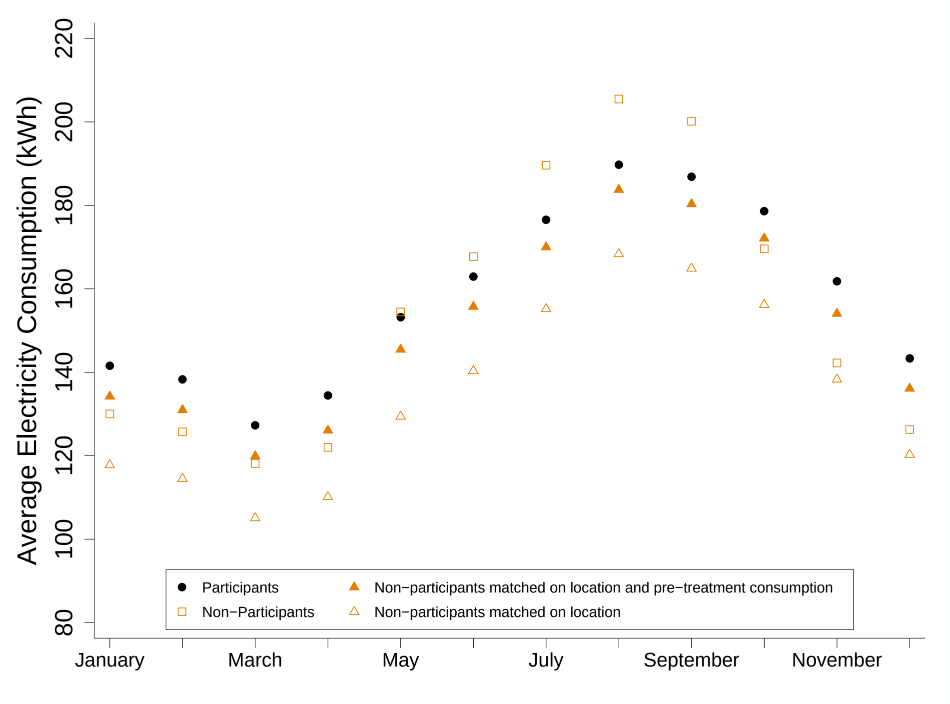
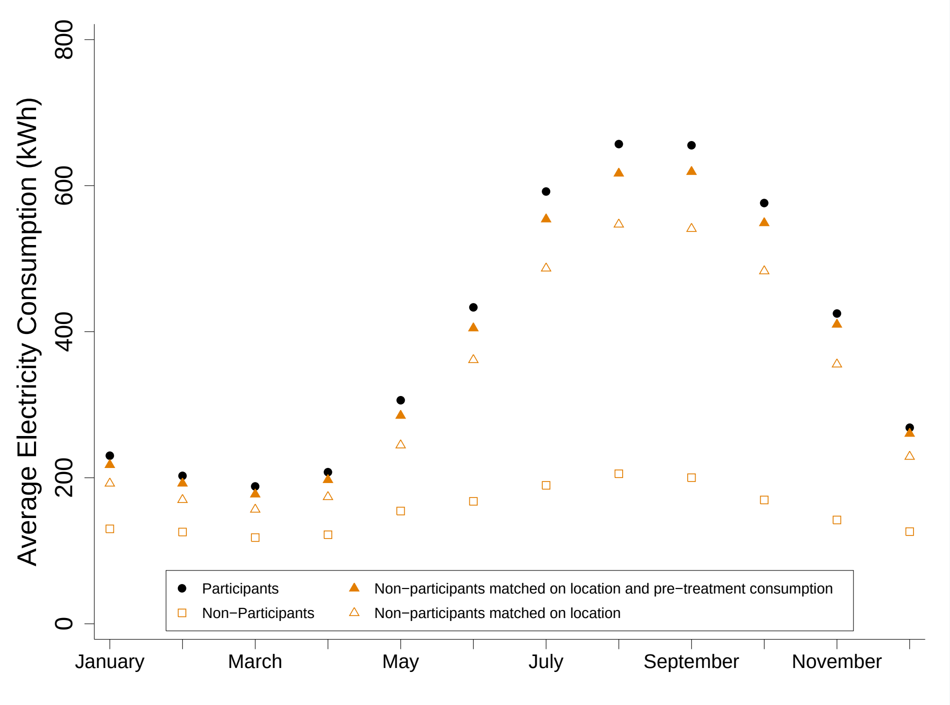


FIGURE 3b

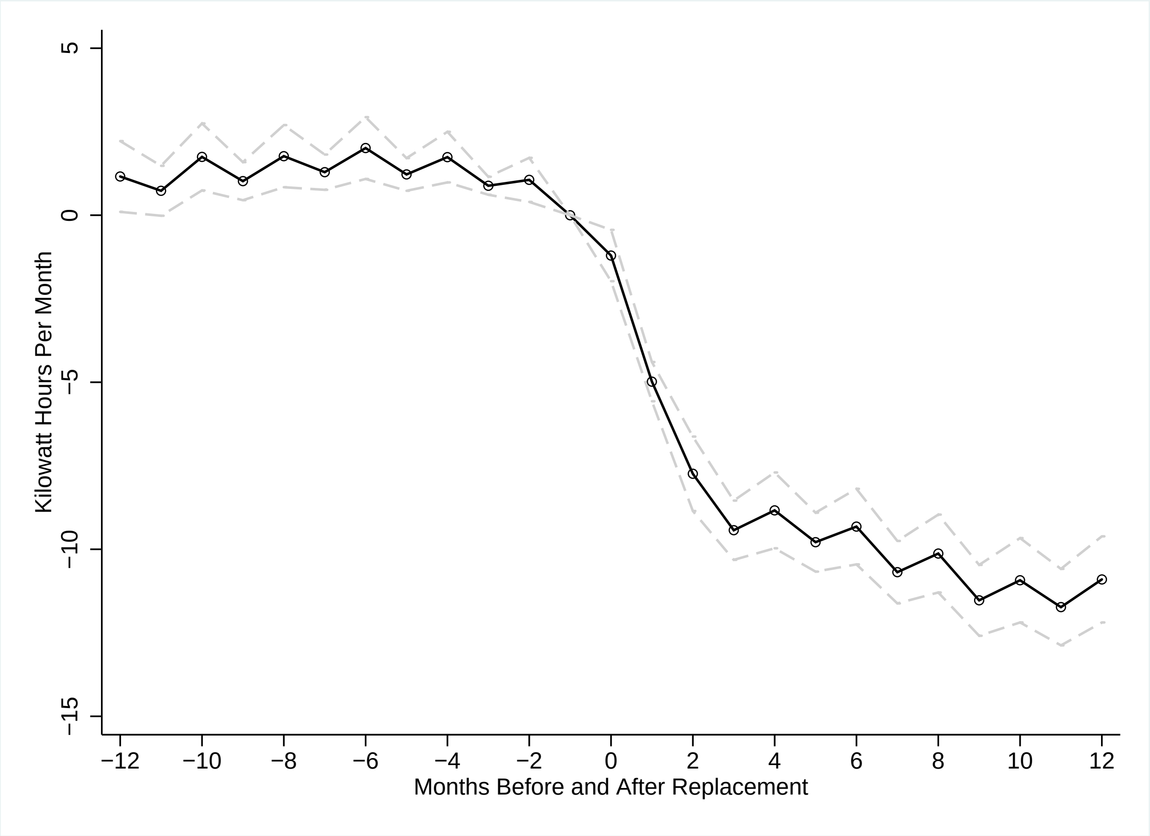
Comparing Participants to Non-Participants: Air Conditioners



Note: These figures plot average electricity consumption by calendar month for households who replaced their refrigerators and air-conditioners through the *C4C* program ("participants"), households who didn't participate in the program ("non-participants"), and for two matched samples of non-participants. For all households the sample is restricted to observations from the first year of the program (May 2009-April 2010). Additionally, for participants the sample is limited to those who participated during the second year of the program (May 2010-April 2011). This restriction ensures that the means for participating households are from before replacement.

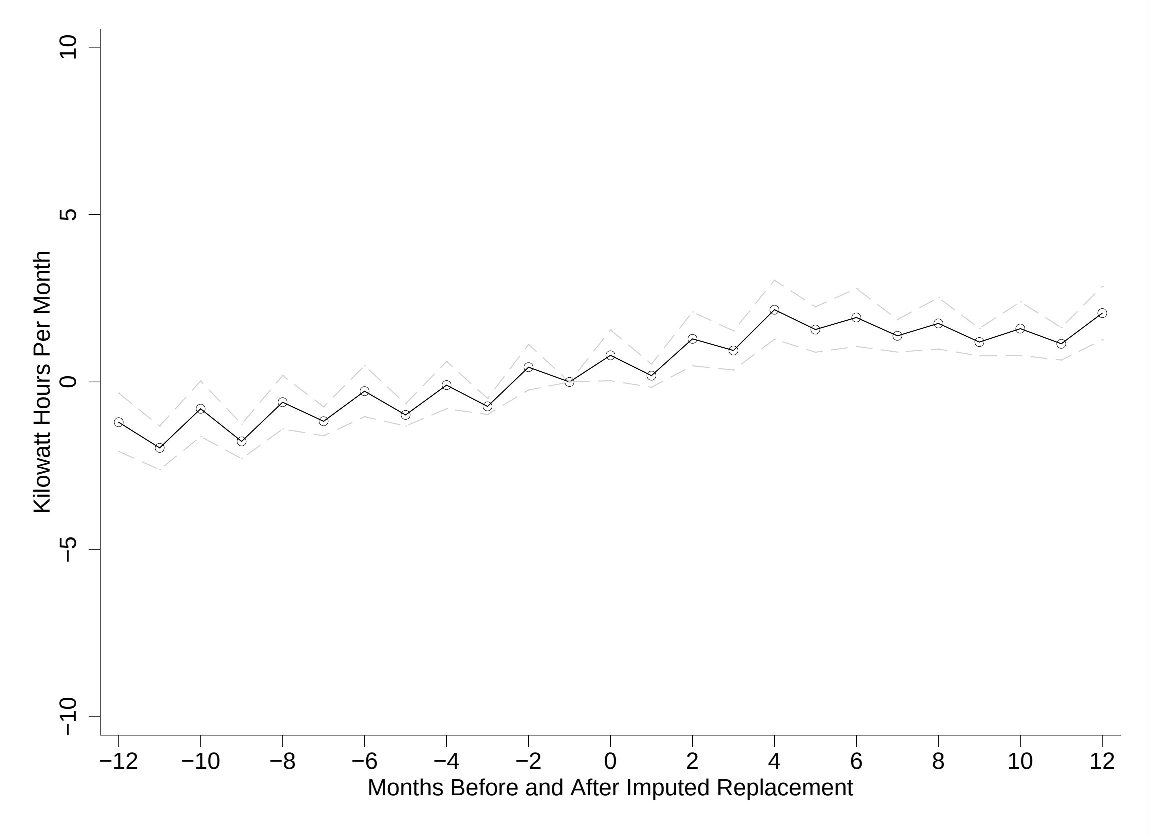
FIGURE 4

The Effect of Refrigerator Replacement on Household Electricity Consumption



Note: This figure plots estimated coefficients and 95th percentile confidence intervals describing monthly electricity consumption before and after refrigerator replacement. Time is normalized relative to the delivery month of the appliance (t=0) and the excluded category is t=-1. Observations from before t=-12 and after t=12 are dropped. The sample includes 858,962 households who received new refrigerators through *C4C* between March 2009 and May 2011 and an equal number of non-participating comparison households matched to treatment households using location and pre-treatment consumption. The regression includes household and county by month-of-sample fixed effects. Standard errors are clustered by county.

FIGURE 5
Assessing the Validity of the Comparison Group



Note: This figure is constructed in the same way as Figure 4 but for the comparison group rather than the treatment group. Non-participating households are assigned hypothetical replacement dates equal to the replacement dates of the participating household to which they are matched.

FIGURE 6A
The Effect of Refrigerator Replacement by Month of Year

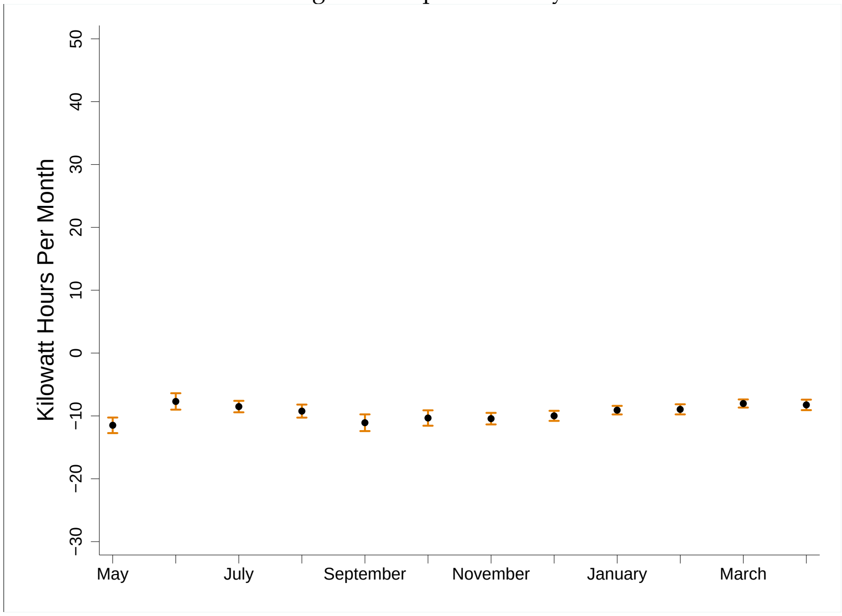
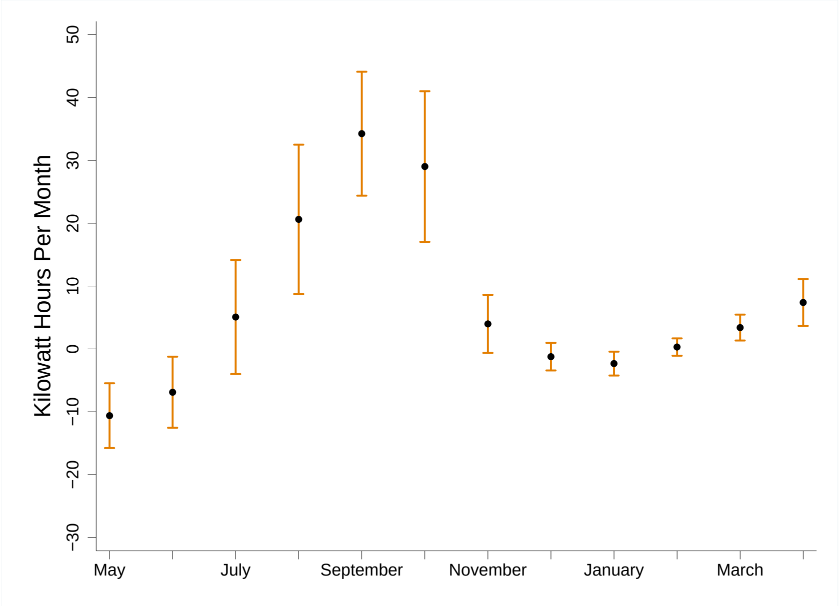
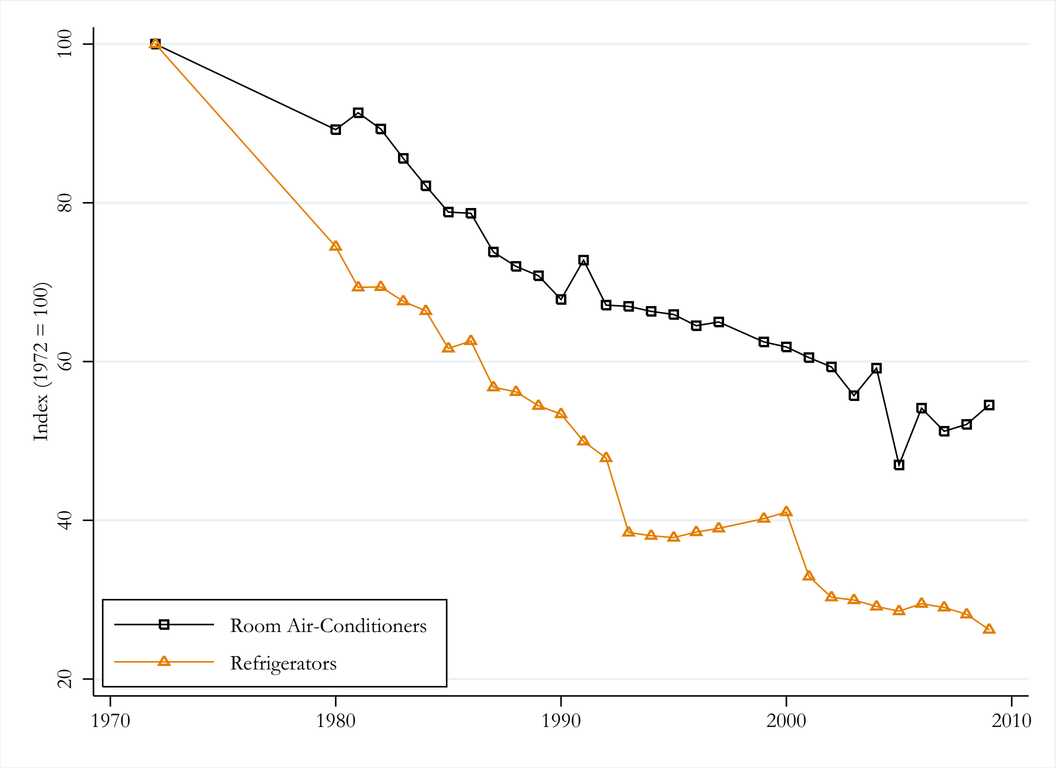


FIGURE 6B
The Effect of Air Conditioner Replacement by Month of Year



Note: Each figure plots estimated coefficients and 95th percentile confidence intervals corresponding to an indicator variable for households that have replaced their appliance from 12 separate regressions, one for each calendar month. The dependent variable in all regressions is monthly electricity consumption in kilowatt hours and the regressions include, in addition household by calendar month fixed effects and month-of-sample by county fixed effects. The sample includes billing records from May 2009 through April 2011. The 1,914,160 households in the complete sample include 957,080 households who participated in *C4C* and an equal number of non-participating households matched on location and pre-treatment consumption. Standard errors are clustered by county.

FIGURE 7
Improvements in Appliance Energy-Efficiency Over Time



Note: This figure plots average electricity consumption for new room air-conditioners and refrigerators shipped for sale in the United States, 1972-2009. Electricity consumption is normalized to 100 at the beginning of the period for both appliances. Between 1972 and 2009, refrigerator electricity consumption decreased from 1716 to 450 kilowatt hours per year, a 74% decrease. During the same period, room air-conditioner electricity consumption decreased from 1271 to 693 kilowatt hours per 750 hours of operation, a 45% decrease. This figure was constructed by the authors using data from various editions of the *Association of Home Appliance Manufacturers Fact Book*. See Nadel (2002) and Rosenfeld and Poskanzer (2009) for similar figures. Data from 1973-1979 are not available. Refrigerators have experienced modest increases in capacity over time, so the figure understates decreases in electricity consumption per cubic foot of capacity.

TABLE 1

Durable Good Saturation Levels By Country

	Refrigerators	Cars	Population (millions)
Brazil (2009)	93%	37%	192
China (2002)	48%	1%	1,325
India (2007/2008)	13%	2%	1,140
Indonesia (2004)	17%	5%	235
Mexico (2008)	83%	29%	111
Sub-Saharan Africa (2006)	11%	5%	578
Total	32%	5%	3,576

Notes: Population is from the World Bank for 2008. Saturation levels come from a variety of country-specific nationally-representative surveys. For sources and additional details see Wolfram, Shelef, and Gertler (2012).

TABLE 2

Demographics and Appliance Saturation in Mexico, Census 2000-2010

	2000 Census	2005 Census	2010 Census
Demographics:			
Total Population (in millions)	97.0	102.8	112.0
Total Number of Households (in millions)	22.6	24.7	28.7
Household Size (persons)	4.3	4.2	3.9
Household Head Completed High School	26.8%	29.6%	32.1%
Number of Rooms in Home	4.32	4.19	4.58
Improved Flooring	86.0%	89.2%	93.9%
Electricity and Appliance Saturation:			
Refrigerator	68.2%	79.1%	82.5%
Washing Machine	51.6%	63.0%	67.0%
Television	85.6%	90.9%	92.6%
Computer	9.2%	19.9%	30.0%
Electricity in the Home	94.7%	96.4%	97.5%

Notes: This table describes data from the Mexican National Census *Censo de Poblacion y Vivienda* from the years indicated in the column headings. These statistics were compiled by the authors using microdata from the long-form survey which is completed by a 10% representative sample of all Mexican households. All statistics are calculated using sampling weights. We have cross-checked total population, number of households, and appliance saturation at the national and state level against published summary statistics and the measures correspond closely. Improved flooring includes any type of home flooring except for dirt floors.

TABLE 3

The Effect of Appliance Replacement on Household Electricity Consumption, Main Results

	(1)	(2)	(3)	(4)	(5)
1[New Refrigerator]$_{it}$	-12.5**	-10.4**	-10.4**	-11.3**	-11.6**
	(0.9)	(0.4)	(0.4)	(0.5)	(0.5)
1[New Air Conditioner]$_{it}$	6.5	6.9**	1.2	1.4	1.0
	(3.8)	(2.0)	(0.7)	(0.8)	(0.9)
1[New Air Conditioner]$_{it}$ x 1[Summer Months]$_{it}$			13.9**	12.1**	14.5**
			(4.0)	(3.9)	(4.1)
Household By Calendar Month Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-of-Sample Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-of-Sample By County Fixed Effects	No	Yes	Yes	Yes	Yes
Including Treatment Households Only	No	No	No	Yes	Yes
Dropping Month of Replacement	No	No	No	No	Yes
Number of Households	1,914,160	1,914,160	1,914,160	957,080	957,080
R^2	.92	.92	.92	.97	.97

Notes: This table reports coefficient estimates and standard errors from five separate regressions. In all regressions the dependent variable is monthly electricity consumption in kilowatt hours and the coefficients of interest correspond to indicator variables for households who have replaced their refrigerator or air-conditioner through *C4C*. The sample includes billing records from May 2009 through April 2011 from the complete set of households that participated in the program and an equal-sized random sample of non-participating households. Mean electricity use is 153 and 395 kilowatt hours per month for households who replaced refrigerators and air conditioners, respectively. Standard errors are clustered by county. Double asterisks denote statistical significance at the 1% level; single asterisks at the 5% level.

TABLE 4

The Effect of Appliance Replacement on Household Electricity Consumption, Matching Estimates

	Matching on Location			Matching on Location and Pre-Treatment Consumption		
	(1)	(2)	(3)	(4)	(5)	(6)
1[New Refrigerator]$_{it}$	-11.1**	-10.8**	-10.9**	-9.5**	-9.3**	-9.3**
	(0.5)	(0.4)	(0.4)	(0.5)	(0.4)	(0.4)
1[New Air Conditioner]$_{it}$	8.0*	6.5**	0.0	9.5**	8.2**	1.9**
	(3.6)	(2.2)	(0.8)	(3.5)	(2.1)	(0.7)
1[New Air Conditioner]$_{it}$ x 1[Summer Months]$_{it}$			15.9**			15.3**
			(4.2)			(4.1)
Household By Calendar Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-of-Sample Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-of-Sample By County Fixed Effects	No	Yes	Yes	No	Yes	Yes
Number of Households	1,914,160	1,914,160	1,914,160	1,914,160	1,914,160	1,914,160
R^2	.93	.93	.93	.92	.92	.92

Notes: This table reports coefficient estimates and standard errors from six separate regressions. In all regressions the dependent variable is monthly electricity consumption in kilowatt hours and the coefficients of interest correspond to indicator variables for households who have replaced their refrigerator or air-conditioner through *C4C*. The sample includes billing records from May 2009 through April 2011 from the complete set of households that participated in the program and an equal-sized matched sample of non-participating households. Matching is performed using location only in columns 1-3 and using both location and pre-treatment electricity consumption levels in columns 4-6. Mean electricity use is 153 and 395 kilowatt hours per month for households who replaced refrigerators and air conditioners, respectively. Standard errors are clustered by county. Double asterisks denote statistical significance at the 1% level; single asterisks at the 5% level.

TABLE 5

Tests of Parallel Trends vs. Alternative Comparison Groups

	(1) All Non-Participants	(2) Non-Participants Matched on Location	(3) Non-Participants Matched on Location and Pre-Treatment Consumption
Coefficient on Pre-Treatment Time Trend for Treatment Group	0.269** (0.0)	0.192** (0.0)	0.285** (0.0)
p-value	.0000	.0000	.0000
Household By Calendar Month Fixed Effects	Yes	Yes	Yes
Month-of-Sample By County Fixed Effects	Yes	Yes	Yes
Number of Households	1,914,160	1,914,160	1,914,160
R^2	0.92	0.93	0.92

Notes: This table tests whether there is a differential time trend for participating households during the pre-treatment period. The table reports estimated coefficients, standard errors, and *p*-values from three separate regressions. The regression specification, sample, and clustering of standard errors is the same as described in Tables 3 and 4 above. Double asterisks denote statistical significance at the 1% level.

TABLE 6

The Effect of Appliance Replacement on Household Electricity Consumption,
Including Time Trends for Treatment Group

	(1) No Time Trend	(2) Linear Time Trend	(3) Quadratic Time Trend	(4) Cubic Time Trend
$1[\text{New Refrigerator}]_{it}$	-9.3**	-11.2**	-11.2**	-11.2**
	(0.4)	(0.5)	(0.5)	(0.5)
$1[\text{New Air Conditioner}]_{it}$	1.9**	0.1	0.1	0.1
	(0.7)	(0.7)	(0..7)	(0.7)
$1[\text{New Air Conditioner}]_{it}$ x $1[\text{Summer Months}]_{it}$	15.3**	15.4**	15.4**	15.3**
	(4.1)	(4.1)	(4.2)	(4.2)
Household By Calendar Month Fixed Effects	Yes	Yes	Yes	Yes
Month-of-Sample By County Fixed Effects	Yes	Yes	Yes	Yes
Number of Households	1,914,160	1,914,160	1,914,160	1,914,160
R^2	0.92	0.92	0.92	0.92

Notes: This table reports coefficient estimates and standard errors from four separate regressions aimed at assessing the robustness of the results with regard to including a parametric time trend for participants. In all regressions the dependent variable is monthly electricity consumption in kilowatt hours and the coefficients of interest correspond to indicator variables for households who have replaced their refrigerator or air-conditioner through *C4C*. The sample includes billing records from May 2009 through April 2011 from the complete set of households that participated in the program and an equal-sized matched sample of non-participating households selected using location and pre-treatment electricity consumption. Standard errors are clustered by county to allow for arbitrary serial correlation and correlation across households within municipalities. Double asterisks denote statistical significance at the 1% level; single asterisks at the 5% level.

TABLE 7

The Effect of Appliance Replacement by Income and Year of Replacement

	Refrigerators	Air Conditioners
A. By Mean Household Income in County		
First Tercile (Less than $5,000/year)	-6.9** (0.2) N=305,669	5.3** (2.0) N=13,202
Second Tercile ($5,000 - $7,637/year)	-10.1** (0.8) N=275,941	7.6** (1.2) N=42,176
Third Tercile (More than $7,637/year)	-11.1** (0.6) N=277,352	9.4* (4.4) N=43,226
B. By Year of Replacement		
Appliance Replaced in 2009	-8.3** (0.4) N=180,507	2.4 (3.1) N=15,267
Appliance Replaced in 2010	-8.6** (0.4) N=497,148	11.3** (2.2) N=59,499
Appliance Replaced in 2011	-4.8** (0.4) N=181,307	9.6** (2.0) N=23,838

Notes: This table reports coefficient estimates and standard errors from six separate regressions, three per panel. In each regression the sample is restricted to a subset of *C4C* participants as indicated in the row headings, along with a matched sample of non-participating households in which matching is performed using both location and pre-treatment consumption. In all regressions the dependent variable is monthly electricity consumption in kilowatt hours. Coefficients are reported from indicator variables for whether the household had replaced their refrigerator or air conditioner. All regressions include household by calendar month and county by month-of-sample fixed effects. Standard errors are clustered by county. Double asterisks denote statistical significance at the 1% level; single asterisk denotes 5% level. The sample sizes indicated above are the number of treatment households in each category. The implied total number of treatment households is slightly larger than the sample size in other tables because 486 households replaced both a refrigerator and an air-conditioner.

TABLE 8

Electricity Expenditures, Carbon Dioxide Emissions, and Cost-Effectiveness

	Refrigerators (1)	Air Conditioners (2)	Both Appliances Combined (3)
A. Mean Per Replacement			
Mean Annual Change in Electricity Consumption Per Replacement (Kilowatt Hours)	-134	92	--
Mean Annual Change in Household Expenditure Per Replacement (U.S. 2010 dollars)	-$13	$9	--
B. Totals			
Total Replacements Nationwide (Between May 2009 and April 2011)	858,962	98,604	957,566
Total Annual Change in Electricity Consumption (Gigawatt Hours)	-115.4	9.1	-106.3
Total Annual Change in Household Expenditures (U.S. 2010 dollars, millions)	-$11.1	$0.9	-$10.2
Total Annual Change in Carbon Dioxide Emissions (Thousands of Tons)	-68.1	5.4	-62.7
C. Cost-Effectiveness			
Total Direct Program Cost (U.S. 2010 dollars, millions)	$129.9	$13.3	$143.2
Program Cost Per Kilowatt Hour (U.S. 2010 dollars)	$0.25	--	$0.30
Program Cost Per Ton of Carbon Dioxide (U.S. 2010 dollars)	$419	--	$502

Notes: Mean annual change in electricity consumption per replacement comes from Table 6, Column (4). Mean annual electricity consumption is 1,836 kilowatt hour per year and 4,740 kilowatt hour per year for households who replaced refrigerators and air conditioners, respectively. Change in expenditures is calculated using an average price of $.096 per kilowatt hour. Carbon dioxide emissions were calculated using 0.59 tons of carbon dioxide per megawatt hour (590 tons per gigawatt hour), the average emissions intensity of electricity generation in Mexico in 2008. Direct program cost is the dollar value of the cash subsidies and excludes administrative costs. In calculating the program cost per kilowatt hour and program cost per ton of carbon dioxide we assumed that the program accelerated replacement by 5 years and adopt a 5% annual discount rate.