CASH FOR COOLERS

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ABSTRACT

This paper examines a large-scale appliance replacement program in Mexico that since 2009 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 population of Mexican residential customers we find that refrigerator replacement reduces electricity consumption by an average of 11 kilowatt hours per month, about a 7% decrease. We find that air conditioning replacement, in contrast, increases electricity consumption by an average of 6 kilowatt hours per month, with larger increases during the summer. To put these results in context we present a simple conceptual framework in which energy-efficient durable goods cost less to operate, so households use them more. This behavioral response, sometimes called the "rebound" effect, is important for air-conditioners, but not important for refrigerators.

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1. Introduction

Supporters of energy-efficiency policies argue that they represent a "win-win", helping participants reduce energy expenditures while also reducing carbon dioxide emissions and other negative externalities associated with energy use.[1] Skeptics of energy-efficiency policies question the magnitude of the potential reductions in consumption and argue that there are important economic costs to energy-efficiency programs that tend to be overlooked.[2] These claims are difficult to evaluate, however, because there is a surprisingly small amount of direct empirical evidence.

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 dollars on energy-efficiency programs between 1994 and 2010, leading to a reported total savings of more than 1 million gigawatt hours of electricity.[3] 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.[4]

Moreover, many low and middle-income countries are now adopting energy-efficiency policies. In part, this reflects a widely-held view that there is an abundant supply of low-cost, high-return investments in energy-efficiency, particularly in developing countries (Johnson, et. al, 2009; McKinsey and Company, 2009b). Over the next several decades most of the growth in global energy demand is expected to come from the developing world. Between 2010 and 2035, energy consumption in non-OECD countries is expected to increase 85%, compared to only 18% in OECD countries.[5] Meeting this increased demand for energy will be a substantial challenge, so understanding the potential role of energy-efficiency is extremely important.

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[1] 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.

[2] For a recent survey see Alcott and Greenstone (2012).

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

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

[5] U.S. DOE (2011a), Table 1. Wolfram, Shelef, and Gertler (2012) argue that energy consumption in non-OECD countries may increase even faster.

In this paper we examine 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 vehicle retirement programs.

The objective of this paper is to quantify the overall impact of *C4C* on electricity consumption and greenhouse gas emissions. To guide the empirical analysis we use a conceptual framework that emphasizes that energy demand 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. Hence, the cost-effectiveness of durable good replacement programs like *C4C* depends not only on the number of households that are induced to replace, but also on the price elasticity of the demand for the underlying services.

We find that refrigerator replacement reduces electricity consumption by an average of 11 kilowatt hours per month, about 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.[6] 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.

We discuss and present ancillary empirical evidence supporting several possible explanations. One important explanation for the differences between our results and the *ex ante* estimates is changes in appliance utilization. This is important for air-conditioners, but not important for refrigerators. In addition, we discuss how increases

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

in appliance size and appliance features (e.g. through-the-door ice) worked to substantially offset the potential reductions in electricity consumption. Finally, we argue that many of the old appliances were probably not working or not working well at the point of replacement.

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."[7] In fact, the primary source of data on energy-efficiency programs in the United States comes from self-reported measures of energy savings from utilities. Economists have long argued that these measures of energy savings are overstated (Joskow and Marron, 1992), yet reporting practices have changed little over time.

A key feature of our analysis is the use of high-quality microdata. For this analysis we were granted access to the census of household-level electric billing records for the population of residential electricity customers in Mexico. There is some precedent for econometric analysis of electric billing data, but this has mostly been in the context of measuring the responsiveness of demand to changes in prices or weather.[8] Moreover, most previous analyses have been of a much smaller scale, for example, using data from a single electric utility. The sheer number of households in our analysis allow us to estimate effects precisely even with highly non-parametric specifications.

The fact that our analysis is based on a large-scale national program gives our results an unusually high degree of external validity. Program evaluation, particularly with energy-efficiency policies, is typically based on small-scale interventions implemented, for example, in one particular location or by one particular utility. In these settings a key question is how well do parameter estimates *generalize* across sites. Moreover, utilities that choose to participate in these programs tend to be considerably

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[7] 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."

[8] See, for example, Engle, Granger, Rice, and Weiss (1986), Reiss and White (2008), and Ito (2011).

different from the population of utilities, raising important issues of selection bias.[9] With *C4C*, we have a program that was available in all Mexican states so our results are nationally-representative.

Our study is among the first to examine energy-efficiency policy in a developing country.[10] To understand energy demand in developing countries it is critical to focus on refrigerators and other appliances. 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). In the near future, we can expect very large number of households to purchase household electric appliances.

The format of the paper is as follows. Section 2 describes a conceptual framework that helps motivate the empirical analyses which follow. 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 concludes.

2. A Conceptual Framework

2.1 Program Design

Before turning to *C4C* it is valuable to briefly lay out a general framework for evaluating appliance replacement programs. When policymakers think about these

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[9] Recent work by Allcott and Mullainathan (2011) provides evidence on the limitations of external validity. Examining 14 nearly-identical energy conservation field experiments in different cities across the United States, they show that estimated effects vary by 240 percent, an amount which is both statistically and economically significant. Moreover, they find strong evidence of selection bias, that electric utilities that choose to participate in these experiments are considerably different from the population of utilities.

[10] 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; and 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).

programs, they typically have in mind a tradeoff between program costs and energy savings and/or environment benefits. Let s denote the subsidy amount per household, N denote the number of participating households, Δx denote the savings in energy consumption per replacement, and let α denote external costs per unit of consumption. Thus the net benefits from an appliance replacement program can be expressed as:

$$(\alpha \Delta x - s)\, N(s).$$

Program effectiveness depends on two key behavioral parameters: (i) program participation, and (ii) energy savings per replacement. This first parameter is the number of households the subsidy induces to replace their appliances who otherwise would not have. While we can observe the number of replacements for a given subsidy, it is difficult to empirically separate households who were truly induced to replace their appliances by the program from inframarginal households who would have replaced anyway. Joskow and Marron (1991) call these households "free riders". Typically even more difficult to measure is this second parameter (Δx). Accordingly, this is where we focus most of our attention in the empirical analysis.

The characterization of the government's objective function above illustrates an important tradeoff in program design. Higher subsidies attract more participants, $\partial N(s)/\partial s > 0$, but only increase net benefits if $\alpha \Delta x > s$. That is, if the value of the avoided external costs per household exceeds the value of the subsidy. This puts a limit on how large of a subsidy should be used. A program that attracts a large amount of participation is of little use if the avoided external costs do not exceed the value of the subsidy. And, even a program that performs well per participant will be of limited value if it cannot be scaled up to a large number of participants.

2.2 How Appliance Replacement Programs Affect Household Energy Use

To evaluate the change in energy consumption per replacement (Δx) we turn to a household production model following Hausman (1979), Dubin and McFadden (1984), and Baker, Blundell and Micklewright (1989). In these models, demand for energy is derived from demand for household services that are produced in the home according to a household production technology. 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,

$$\max_{\{j\,\in 1,\ldots,J\}} \{V(\theta_1), \ldots, V(\theta_J)\},$$

where V is a conditional indirect utility function and θ_j is a vector of characteristics for durable good portfolio j. Portfolios differ in terms of characteristics θ_j and rental prices r_j. Appliance replacement programs like *C4C* affects portfolio choices by changing 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,

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

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

$$px + z_2 = y - r_j$$

As in the original household production problem described by Becker (1965), this 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.[11]

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[11] 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.

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.[12] This is a significant analytical improvement because the household's problem may be treated as a classic demand problem,

$$V(\theta_j) = \max_{\{z_1, z_2\}} \; U(z_1, z_2)$$

$$\pi(p \mid \theta_j)\, z_1 + z_2 = y - r_j$$

where $\pi(p \mid \theta_j)$ is the marginal cost of producing z_1. 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. Under these conditions, the solution to the household's conditional utility-maximization problem is described by demand functions for household services (z_1) and the composite good (z_2), as well as a conditional demand function for energy,

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

Conditional on the characteristics of the household production technology (θ_j) this function describes how demand for energy demands on input prices and net income.

2.3 The Rebound Effect

The decrease in energy consumption in response to the adoption of an energy-efficient durable good can now be expressed,

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

where θ_{old} and θ_{new} denote the characteristics of old and new durable goods, respectively. Ignoring income effects which are likely to be small, there are two primary

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Another important complication that comes up in our context is nonlinear input prices. As we explain later, electricity is sold using increasing block rates. This nonlinearity tends to amplify the behavioral responses to energy-efficiency policy by moving households to lower marginal rates.

[12] In the presence of nonconstant returns to scale, marginal cost depends on the level of production and the feasible set is no longer a straight line. As a result, even if preferences are strictly convex, there may be multiple solutions and the demand function need not be continuous in price (Pollak and Wachter, 1975). Joint production occurs when the cost of producing a particular household service depends on the level of production of another service. With residential energy cost dependencies could arise in several ways. For example, the amount of electricity used by a refrigerator depends on ambient temperature, and thus the level of production of air-conditioning. In the empirical analyses we can test for this directly.

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 produced with that durable good. Energy-efficient durable goods cost less to operate so households may use them more. This second mechanism is indirect but not necessarily smaller in magnitude than the first mechanism. Which effect is larger depends on the price elasticity of demand for the underlying household service, z_1.

Sometimes called the "rebound" effect, this idea that improvements in energy-efficiency may lead to increased utilization goes back at least 150 years.[13] 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 the price elasticity of utilization exceeds one.[14] Others have argued that utilization elasticities are considerably smaller.[15] 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 likely to be inelastic. Refrigeration is a good example. A household can switch entirely to non-perishable food but this requires a drastic change in diet and likely 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

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[13] 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, Khazzoom (1980), Hartman (1981), and Hausman and Joskow (1982).

[14] See, for example, Inhaber (1997), Strassel (2001), and Owen (2010).

[15] See, for example, Schipper and Grubb (2000). Davis (2008) finds a price elasticity near zero for clothes washing using quasi-experimental data from a field trial, and argues that there are a large and growing number of residential services that are time-intensive and thus likely to be relatively inelastic with respect to energy costs.

ventilation, shut curtains during the day, spend more time outdoors or at work, or wear different clothing.

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 the overall level of utilization. Consider air-conditioning as an example. Above a certain income level, a household is going to choose to maintain the ideal level of thermal comfort at all hours of the day regardless of energy costs and the price elasticity of utilization for these households is very low. At lower income levels, however, households choose to operate 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.

3 C4C

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 of the 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 (basic, intermediate, and high). The rates for the second and third tiers are approximately two and four times the rate in the first tier. The rates for the different tiers vary over time but are the same nationally for all households.[16] In addition, for households with consistently high levels of electricity consumption there is an alternative schedule which replaces the increasing block rates with a flat charge per kilowatt hour similar to the third tier rate.[17]

Residential electricity consumption is subsidized by the Mexican Federal government. Prices on the first tier tend to be very 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.[18] The Mexican Energy Ministry estimates that residential customers face a price that is, on average, about half the average cost of providing power.[19]

Electricity consumption per capita is low but increasing rapidly. Average per capita electricity consumption for Mexico is 1,900 kilowatt hours annually, compared to

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[16] Consumption thresholds for these different blocks vary across households based on the average summer temperature where the household lives and the month of the year. There are seven different residential tariffs (1, 1A, 1B, 1C, 1D, 1E, and 1F). Each has different baselines for the three tiers based on average summer temperature. Customers subject to tariff 1 (mean summer temperature below 25 degrees Centigrade) face the same thresholds all year. All other households (1A, 1B, 1C, 1D, 1E, and 1F) have higher baselines during the six hottest months of the year. Moreover, *which* six months receive this higher baseline varies across geographic area. Geographic areas with higher temperatures have higher baselines.

[17] The alternative schedule (*Tarifa Doméstica de Alto Consumo*) is designed to eliminate the government subsidy entirely for these households with a fixed rate approximately equal to the third-tier rate. Households are automatically switched into this alternative rate schedule if their average monthly consumption over the previous twelve months exceeds a threshold. This threshold varies across regions within Mexico. For example, in 2011 the minimum threshold for the alternative schedule was 250 kilowatt hour per month for region 1, and 2,500 kilowatt hour per month in region 1F. This change to the alternative schedule is not permanent and if a household's average consumption over the previous 12 months drops again below the threshold the household is automatically switched back to the regular schedule.

[18] 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.

[19] 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 has explained that these losses average approximately 23%, so to provide 100 kilowatt hours CFE must generate about 130.

13,600 for the United States.[20] Over the next several decades, electricity generation in Mexico is forecast to increase 3.2% per year, almost quadruple the rate forecast for the United States.[21] This is pretty typical for developing countries. Electricity demand in non-OECD countries is forecast to increase by 3.3% annually over the same period, compared to 1.2% annually for OECD countries.

Growth in residential appliances is one of the major drivers of this increase in demand. Figure 1 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. Again, this is typical of developing countries and policymakers worldwide are making appliance energy-efficiency a major point of emphasis (Gertler, Shelef, Wolfram and Fuchs, 2011). 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.[22]

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 generation and transmission infrastructure between 2010 and 2025.[23] 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.

Much of the promise of *C4C* is based on *ex ante* engineering analyses that estimate that replacements should lead to substantial decreases in electricity consumption. In independent studies of available energy-related investments in Mexico both the World Bank and McKinsey concluded that replacing residential refrigerators and air-

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[20] Electricity consumption per capita comes from World Bank, *World Development Indicators* for 2008. Mexican per capita consumption is similar to Brazil (2,200) and somewhat lower than Argentina (2,800). These measures are total electricity consumption divided by population and thus include residential, commercial, and industrial electricity consumption.

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

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

[23] 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).

conditioners would be extremely cost-effective.[24] 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 will revisit these predictions below, contrasting them with the results from our empirical analysis.

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.[25] 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.[26]

This is nationwide program. Subsidies are available for both refrigerators and air conditioners, but 90%+ of the replacements to date have been refrigerators. To

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[24] See Johnson, et. al (2009), Figure 2 and McKinsey and Company (2009b), Exhibit 4. This McKinsey report is focused on Mexico, but is otherwise similar to McKinsey and Company (2009a) that is focused on the United States. These reports are the latest in a long series of engineering studies going back at least to Meier, Wright, and Rosenfeld (1983) that conclude that there is a large amount of energy that can be conserved at *negative* net cost. That is, that there are energy-efficiency investments that would pay for themselves, even before incorporating potential external benefits.

[25] 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.

[26] The official name of the program is *Programa de Sustitución de Equipos Electrodomésticos para el Ahorro de Energía*. Mexican President Felipe Calderon speaks frequently about the program and in April 2011 attended a ceremonial awarding of the 1,000,000th refrigerator. See El Economista, "Calderón Entrega Refrigerador Un Millón", April 11, 2011.

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 appliance is delivered. Households are eligible to replace only one appliance of each type. And, the new appliances must meet certain size requirements.[27] 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. For refrigerators, the relevant standard was established in 2002.[28] For air-conditioners the relevant standard was established in 2008.[29]

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 (see Appendix Table 1). To qualify for the more generous subsidy a household needs to have a fairly 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

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[27] 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.

[28] Mexico's first refrigerator standards were implemented in 1994 (NOM-072-SCFI-1994) with minimum efficiency requirements identical to U.S. standards for most refrigerator classes. These standards, including the exact testing methodology and size classifications were based closely on U.S. standards first introduced in 1990 (42 U.S.C. 6295) and updated in 1993 (54 FR 47916). Mexican refrigerator standards were updated in 1997 (NOM-015-ENER-1997) after which minimum efficiency standards were essentially identical in both countries for all refrigerator classes. The Mexican 2002 standard (NOM-015-ENER-2002) is identical to updated U.S. standards implemented in 2001 (62 FR 32102). New U.S. standards for refrigerators will take effect in 2014 (76 FR 179).

[29] Mexico's energy-efficiency standards for air-conditioners were first implemented in 1995 (NOM-073-SCFI-1994) then updated in 2001 (NOM-021-ENER/SCFI/ECOL-2000). These standards are identical to U.S. standards implemented in 1990 and 2000 (10 CFR 430). The 2008 Mexican standard (NOM-021-ENER-2008) is identical to the 2001 standard except for updated testing procedures and other minor refinements. More stringent standards for room air-conditioners became effective in the United States in August 2011. The air-conditioners replaced under *C4C* are either room air-conditioners or ductless "mini-split" air-conditioners which use an outside compressor connected to an indoor unit. These systems are similar to central air-conditioners in that they use both indoor and outdoor units, but do not use ductwork. Central air-conditioning is relatively uncommon in Mexico and not part of *C4C*.

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 quality 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.

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.[30] 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.

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

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[30] 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.

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.[31] 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.[32] 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*.[33] This back-of-the-envelope calculation is based on a linear 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 "free riders" i.e. households who would have replaced their appliances even in the absence of the subsidy. It is worth emphasizing, however, that even in these cases one should expect the program to 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%. Had they not been used in the program, many of these appliances would have otherwise been resold in secondary markets.[34] Permanently destroying the appliances removes them from the stock,

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[31] See Arroyo-Cabañas, et al. (2009), Table 3. As of 2007, there were 23 million refrigerators owned nationwide. Of these, 57% were less than 10 years old, compared to 28% between 11 and 20 years old, and 15% more than 20 years old.

[32] 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).

[33] This increase in sales also suggests that the economic *incidence* of the subsidy is largely on households. This makes sense given the structure of the market. 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 ramp up production in response to increases in demand.

[34] In a closely related market Davis and Kahn (2010) document that vehicle retirement rates in Mexico are substantially lower than in the United States. For example, the mean annual retirement rate for 10-30 year old vehicles is 12.2% in the United States compared to only 3.8% for Mexico. This likely reflects several different factors including differences in income levels and thus demand for quality, energy subsidies, and

preventing them from using additional electricity regardless of whether they would have stayed with their primary owner.

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. The Mexican National Income and Expenditure Survey ("ENIGH") also asks households about appliance ownership and in ENIGH between 2000 and 2008, the total number of households with refrigerators increased by 5.2 million (see Appendix Table 3), compared to 12.1 sales of new refrigerators. 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.

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 bimonthly electricity billing records.[35] These data describe bimonthly electricity consumption and expenditure for all 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

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differences in repair costs.

[35] 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 the CFE.

(<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 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

The main empirical challenge in analyses of energy-efficiency has been the lack of high-quality microdata. Utilities are often reluctant to share billing data of the form used in this analysis and analyses with more aggregate data struggle to credibly distinguish the impact of policies from other determinants of energy consumption that are changing over time. Thus a significant part of the contribution of this analysis is simply bringing the relevant data to bear.

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 as a comparison group households living in the same county. 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,

$$y_{it} = \beta_0 + \beta_1 1[New\ Refrigerator]_{it} + \beta_2 1[New\ Air\ Conditioner]_{it} + \gamma_{i,moy} + \omega_t + \varepsilon_{it}.$$

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 each household we have about 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 $-\Delta x$ in the conceptual framework.

Most of the estimates that we report 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).[36] 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, these fixed effects capture the fact that some households have air-conditioning

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[36] 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.

and some do not, and that demand for air-conditioning varies differentially across the year for different households.

The estimates that we report also include month-of-sample fixed effects ω_t. This controls for year-to-year differences in weather as well as for population-wide trends in electricity consumption, for example, driven by increased saturation of durable goods throughout this period for reasons that have nothing to do with *C4C*. Many specifications, in addition, include month-of-sample by county fixed effects. 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.

Most specifications include a group of control households that we matched to the treatment households using account numbers. The way account numbers are structured they identify not only the state and county where the household lives, but also the specific route used by meter readers. For each *C4C* participant, we select the account corresponding to the closest consecutive non-participating housing unit. In many cases this is the household living immediately next door. In some cases a non-participating household is selected as the control for more than one treatment household. These matched households are a better comparison group than had we used the entire set of non-participating households because of their close physical proximity to the treatment households (see Figure 2). Weather is a major determinant of electricity consumption so this matching ensures, for example, that the distribution of counties of residence among the control households is the same at the distribution among treatment households. Because our preferred specifications include month-of-sample by county fixed effects, identification comes from *within-county, within-month* comparisons between treatment and control households.

We also report estimates from regressions that are estimated using only households that participated in *C4C*. In these specifications we simply drop all control households and the effects of *C4C* are identified using within-household changes in electricity consumption. We continue to include month-of-sample by county fixed effects to control for time effects. This is possible because households replaced their appliances at different times during the sample period.

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 the "event study" analysis performed here. 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 3 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 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 β from the following regression,

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

where τ_{it} denotes the event month defined so that τ=0 for the exact month in which the refrigerator is delivered, τ=-12 for one twelve months before replacement, τ=12 for twelve months after replacement, and so on. The coefficients are measured relative to the excluded category (τ=-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 is confounded with seasonal effects as well as slow-moving population-wide changes in residential electricity 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 actually every other month, and to a modest amount of measurement error in the replacement dates. The gradual decline between months +2 and +12 reflects modest compositional changes in the treatment households.[37] In all periods the coefficients are estimated with enough precision to rule out small changes in consumption in either direction.

With Figure 4 we perform the exact same exercise but using households who did not participate in *C4C*. Our sample is the set of all households that were matched to households that replaced their refrigerators. We assigned each household the replacement date of the household to which that household is matched. We then constructed event time before and after *t=0* exactly as we did for Figure 3. The figure exhibits no discernible pattern with estimated coefficients near zero and statistically insignificant in all months, providing additional corroboration that our fixed effects are adequately controlling for seasonal effects and underlying trends.

5.2 Baseline Estimates

Table 3 presents our main results. The table reports least squares coefficients and standard errors from six separate regressions. The specification described in column (1) includes household by calendar month and month-of-sample fixed effects. In this specification, refrigerator replacement decreases electricity consumption by 11.2 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 a 7% decrease. Whereas

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[37] We show later that households who replaced refrigerators early in the program tended to save more electricity after replacement. These households are disproportionately represented as one moves from left to right in the figure. For example, whereas all treatment households are observed at t=0, only households who replaced during the first year are represented at t=12.

refrigerator replacement decreases electricity consumption, the estimates indicate that air-conditioning replacement *increases* consumption by about 8.5 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 refrigerators remains about the same and the point estimate for air-conditioners decreases 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 16.5 kilowatt hours per month.

The difference in difference estimates use the change in the comparison group to estimate what would have been the change in the treatment had the treatment group not received the intervention – i.e the counterfactual. This assumes that the change is an unbiased estimate of the counterfactual and is not testable. However, we can test whether the changes over time in the treatment group are the same as those in the control group in the pre-intervention period. It the time trends of the two groups are not different in the pre-intervention period, then they would likely be the same in the post-intervention period. However, we do find small but statistically significant differences in pre-intervention period. A common correction for this is to include a linear time trend for program participants. The results are essentially unchanged when in column (4) we do indeed include a linear time trend for participants following Heckman and Hotz (1989). In Appendix Table 2 we report results from including a quadratic and cubic polynomial time trend for participants and results are again similar. This suggests that the statistical significance is driven more by our large sample size rather than meaningfully differential trends.

Columns (5) and (6) present results from alternative specifications. In both columns we drop all control households, and estimate the regressions using only households who participated in the program. Column (6), in addition, drops the month during which replacement occurred. In these regressions, we are controlling for time effects by exploiting differential *timing* of replacement across sample months. The estimates change little in these specifications, suggesting that what matters most in these regressions is the within-household comparison. In additional results, not reported, we have also estimated regressions using a *random* sample of non-participating households.[38] Results are again very similar. Although we prefer to use the *matched* comparison group, we find it reassuring that the results are similar regardless of which comparison group we use, or whether we use a comparison group at all.

5.3 Heterogeneous Effects

Table 4 presents estimates for different subsets of participants. The table reports estimates and standard errors from six separate regressions. Coefficients are reported from indicator variables for refrigerator and air conditioner replacement and 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.[39] For refrigerators, the estimates are negative and statistically significant for all three income terciles with the largest decreases observed in the highest-income counties. For air-conditioners, the estimates are positive and statistically significant in two out of the three income terciles.

Panel (B) presents estimates separately by the year of replacement. *C4C* was launched in 2009 and we have in our analysis replacements made during each of the first three years of the program. Point estimates tend to increase across years consistent with *newly* eligible households tend to have less to gain from replacement, and as time goes

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[38] An additional possible specification would be to use a matched comparison group, in which the matching is done both on geography and historical electricity usage. Given the insensitivity of our results, however, we think that this would be highly unlikely to change the results. Moreover, matching on the basis of historical consumption would require us to exclude households who replace in the first couple of months in our sample.

[39] We merged in the 2010 Mexican Census data using state and county names. For 93% of households there was an exact match for both state and county. Requiring an exact match for the state and using probabilistic string matching for the county we increased this to 98%. For the remaining 2% of households we used the mean characteristics of the state.

on an increasing proportion of the participants are those that just barely meet the eligibility requirements. For example, with appliances that are exactly 10 years old in 2010 or 2011.

Continuing to explore heterogeneity in the effect of appliance replacement we now turn to variation across months of the year. Figures 5A and 5B plot the effect of appliance replacement by month of year. For refrigerators the estimates are similar across calendar months. Engineering studies have found that ambient temperature is an important driver of refrigerator electricity consumption (see, for example, Meier 1995), but the *change* in consumption after replacement seems to be reasonably similar during hot and cold months. For air-conditioning, estimates vary substantially across months. Estimates are 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.

5.4 Comparing Our Results to Ex Ante Predictions

Available *ex ante* analyses predicted that the savings from appliance replacement would have been considerably larger. For example, the World Bank study 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.[40] 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 132 kilowatt hours per year, about one-quarter of the savings predicted by the World Bank.[41] And for air-conditioning, we are finding that after replacement electricity consumption *increases* by about 80 kilowatt hours per year.

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[40] 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 calculates that replacing pre-2001 Mexican refrigerators would reduce electricity consumption by an average of 315 kilowatt hours per year.

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

One important explanation for the differences between our results and the *ex ante* estimates is 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 "rebound" effect for air conditioning. Suppose that before *C4C* households used their air-conditioners an average of 750 hours per year.[42] This is slightly more than 2 hours per day for the entire year or 4 hours per day for half the year. Room air-conditioner energy-efficiency has improved 13% over the last ten years.[43] Absent any change in utilization, therefore, air-conditioning replacement should save about 100 kilowatt hours per year. Instead, we see an *increase* of 80 kilowatt hours per year. For this to be explained entirely through increased utilization would require a 26% increase in utilization. Thus if the observed changes in electricity consumption associated with air-conditioner replacement were to be explained entirely via an increase in utilization, the price elasticity would need to be about - 2. Although we don't think an elasticity of - 2 is entirely implausible, this is considerably larger than previous estimates in the literature.[44] Instead, we think it is more likely that a combination of factors tended to push up electricity consumption both for refrigerators and for air-conditioners.

First, it seems likely that some of these refrigerators and air-conditioners may not have been working or not working well at the point of replacement. Appliances were supposed to be in working order to be eligible for the program, but enforcement was likely less than 100%. And even for air-conditioners that were "working", there were likely some that were not working well, perhaps because they needed new refrigerant or other forms of maintenance.[45]

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[42] This follows Association of Home Appliance Manufacturers (2010) which assumes that room air-conditioners are used 750 hours per year.

[43] According to the Association of Home Appliance Manufacturers (2010), for 750 hours of operation the average shipment-weighted electricity consumption for room-air conditioners has decreased from 794 to 693 kilowatt hours per year.

[44] For example, Hausman (1979), finds that the elasticity of utilization for room air-conditioners is 0.27. It is worth highlighting, however, that like most of the existing empirical work in this area, this estimate comes from the United States. At lower income levels and lower baseline utilization levels the price elasticity is going to be higher. Particularly important is where a household is relative to its "bliss point" for ambient temperature. A household far away from its optimal level for thermal temperature has more scope to change utilization in response to an improvement in energy-efficiency.

[45] Here there is a bit of 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

Second, 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. Similar requirements were imposed for air conditioners. Again, however, it is likely that enforcement was less than 100%. Moreover, even the modest increases in size allowed under the rules would be expected to partially offset the potential efficiency gains. Minimum efficiency standards both in the United States and in Mexico are *functions* of the total adjusted volume, with each additional cubic foot adding 10 kilowatt hours per year.[46]

Third, appliance features have expanded over time. 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.[47] Air-conditioners have become quieter, and added features like lower cycle speeds (for operating a night), and remote control operation. These features make air-conditioners easier and more convenient to use, likely leading to increased utilization.

Fourth, there is no evidence that the program was particularly 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.[48] The average reported age for air-conditioners is 10.9 years and only 5%

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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.

[46] The current standard both in the United States and Mexico specifies that refrigerators with top-mounted freezer and automatic defrost without through-the-door ice has a maximum energy use of $9.80AV+276.0$ where AV is the total adjusted volume in squared feet. Under *C4C* refrigerators had to be between 9 and 13 cubic feet, implying a range of minimum consumption from 364 to 403 kilowatt hours per year.

[47] Current energy-efficiency standards both 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 squared feet. The equivalent formula for refrigerators with through-the-door ice is $10.20AV+356.0$.

[48] There are a couple of possible explanations for the apparent lack of success at targeting very old refrigerators. One possible explanation lies in the eligibility criteria themselves. As we discussed earlier, the

of the air-conditioners that were replaced are more than 15 years old. There is likely to be a large amount of measurement error in these self-reported ages, but this apparent lack of success at targeting very old appliances is potentially important because energy-efficiency has improved steadily over time (see Figure 6).[49]

6 Cost-Effectiveness

6.1 Baseline Estimates

Table 5, Panel (A) reports the mean annual impacts implied by our estimates. Refrigerator replacement reduces electricity consumption by 132 kilowatt hours annually, while air-conditioner replacement increases electricity consumption by 79 kilowatt hours per year. At average residential electricity prices, refrigerator replacement saves household \$13 annually, while air-conditioner replacement costs households an additional \$8 annually.[50] Residential electricity prices in Mexico are subsidized, so some have argued that the total economic value of these changes could be considerably larger. However, it is important to distinguish carefully between *average* and *marginal* costs. About half of the cost of electricity is the fixed cost of transmission and distribution infrastructure and these costs do not change when there is a reduction in electricity demand along the intensive margin.

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-conditioning replacements. Our estimates imply that total reduction in electricity consumption associated with the program is about 100 gigawatt hours annually. As a

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size of the subsidy is decreasing in household electricity consumption. This means that, ironically, households with very inefficient appliances tend to not qualify 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 borrowing constraints or other factors.

[49] These data describe shipments of refrigerators in the United States. Equivalent data for Mexico are not available but likely to be very similar given that the countries have identical energy-efficiency standards and that a substantial share of appliances sold in Mexico are imported from the United States. The U.S. data is also broadly consistent with Arroyo-Cabañas, et al. (2009) who report that consumption for Mexican refrigerators has decreased 60% since refrigerators sold prior to 1980, 50% since 1981-1990, 40% since 1991-1994, and 30% since 1995-2000.

[50] These estimates were calculated using the estimates in Table 3, Column (2) multiplied by 12 to reflect annual changes. To calculate household expenditure we used 9.6 cents per kilowatt hour, the average price of electricity for Mexican residential customers.

point of comparison, residential sales nationwide in Mexico totaled 49,000 gigawatt hours in 2009.[51] At average residential electricity prices this implies total savings of about $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.[52] Electricity generation in Mexico is somewhat less carbon-intensive than in the United States, reflecting in part the fact that Mexico has a higher fraction of hydropower.[53] The total decrease in carbon dioxide emissions implied by our estimates is 62 thousand tons of carbon dioxide annually.[54] Using a conservative estimate for the social cost of carbon dioxide ($20 per ton) this implies an additional $1.2 million in benefits annually.[55]

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

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

[52] 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).

[53] From U.S. DOE (2011c), Table 12.7a "Emissions from Energy Consumption for Electricity Generation" total carbon dioxide emissions in 2008 for electricity generation were 2.48 billion metric tons. From Table 8.2a "Electricity Net Generation," total electricity generation was 3.95 trillion kilowatt hours. Thus each megawatt hour of electricity generation implies approximately (2.48) / (3.95) = .63 metric tons of carbon dioxide emissions.

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

[55] 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.

program design, administration, advertising, or other indirect costs. Evidence from previous studies indicates that these indirect costs are important (Joskow and Marron, 1992). Dividing these costs 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 $460 compared to $506. 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 "free riders", i.e. households who would have replaced their appliances anyway, in which case the program does not accelerate replacement at all and 5 years is too generous. On the other hand, even for "free riders", the program prevents appliances from being resold to other households who might have 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 $283 compared to $506.

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.[56] Had the refrigerator replacements saved 63 more kilowatt hours per year, the program cost per kilowatt hour (for refrigerators) would have been $0.17 compared to $0.25, and the program cost per ton of carbon dioxide (for refrigerators) would have been $289 compared to $427.

6.2 Discussion and Limitations

These estimates of the program cost per kilowatt hour avoided and per ton of carbon dioxide abated are high compared to most available 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.[57] 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 9 times larger. Allcott (2011) reports cost-effectiveness measures for peer-comparison programs from OPOWER ranging from 2-5 cents.

With regard to carbon dioxide abatement an important point of comparison is *Cash for Clunkers*.[58] 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.

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[56] The current standard both in the United States and Mexico specifies that refrigerators with top-mounted freezer and automatic defrost without through-the-door ice has a maximum energy use of $9.80AV+276.0$ where AV is the total adjusted volume in squared 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.

[57] U.S. DOE (2011b), Tables 9.6 and 9.7.

[58] 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, forthcoming).

Recent work by Mian and Sufi (forthcoming) finds that the effect of the program on auto purchases was almost completely reversed by as few as 7 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 by much larger.

It is important to emphasize that program cost per kilowatt hour avoided and program cost per ton of carbon dioxide abated are both measures of cost-effectiveness, and do not capture the full set of welfare implications of a program like *C4C*. Although commonly used in previous studies of energy-efficiency, these measures miss several important program components on both the cost and benefit side, and don't carefully distinguish between private and social costs and benefits. For example, a substantial benefit from the program is that households receive utility from using newer, more feature-rich appliances. With refrigerators, households enjoy better insulation, and in some cases automatic ice-makers, through-the-door water and ice and other features. There may even be modest health benefits in the form of improved cooling and temperature consistency leading to less spoilage. These increases in utility were not the primary objective of the program, but they are a substantial source of benefits.

These measures also capture only some of the total costs of the program. These measures of cost-effectiveness include the direct cost of the subsidies, but not the indirect costs from administering the program. Another important component in the full welfare analysis is the private costs borne by households to purchase these appliances. Even the households in *C4C* who qualified for the most generous subsidies ended up paying for a large part of the price of these appliances out of pocket. A comprehensive welfare analysis would also want to take into account the costs borne by buyers in the secondary market. These households are perhaps the biggest losers from the program, now without access to the over one 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 electricity rates are subsidized.

The sense in which these cost-effectiveness numbers make sense is, instead, as a metric for comparing tradeoffs between government expenditure, electricity consumption, and the environment. As we framed at the beginning, when policymakers envision appliance replacement programs they typically have in mind these tradeoffs, so it makes sense to evaluate the program on this basis. And, along this dimension, *C4C* is an expensive policy. Viewed as strictly a tradeoff between government expenditure and the environment, the Mexican government could do much better buying permits in the European Union Emissions Trading System and tearing them up. As of March 2012, the price of a permit is about $10 per ton. Thus, purchasing permits and tearing them up would allow the Mexican government to "buy" carbon dioxide abatement at a cost about 1/50th the cost of *C4C*.

7. Conclusion

At first glance, there would seem to be much to like about an appliance replacement program like *C4C*. Over the last 30 years residential appliances have experienced unprecedented gains in energy-efficiency, so there would seem to be scope for these programs to substantially decrease energy consumption. Moreover, residential appliances like refrigerators are long-lived durable goods with a low baseline replacement rate, 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 program results. 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* analyses. Even larger decreases were predicted for air-conditioners, but we find that households who replace their air-conditioners actually end up increasing their electricity consumption. Our results indicate that *C4C* reduces electricity consumption at a program cost of about $.30 per kilowatt hour, and reduces carbon dioxide emissions at a program cost of about $500 per ton.

These results underscore the urgent need for careful modeling of household behavior. 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. A nice feature of the analysis is that refrigerators and air-conditioners occupy different ends of the spectrum along this dimension, making comparisons particularly interesting.

Households receive utility from using these appliances, and they can and should increase utilization when upgrading to more energy-efficient appliances. 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.

More broadly our results point to several lessons for the design and evaluation of energy-efficiency policies. Over time appliances 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. Also, despite attempts by administrators to build enforcement mechanisms into the program design, it is difficult to prevent people from receiving subsidies for non-working durable goods. While one can envision third-party enforcement mechanisms, this would add cost to the program and be susceptible to fraud.

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FIGURE 1

Durable Good Ownership Rates by Income Level in Mexico

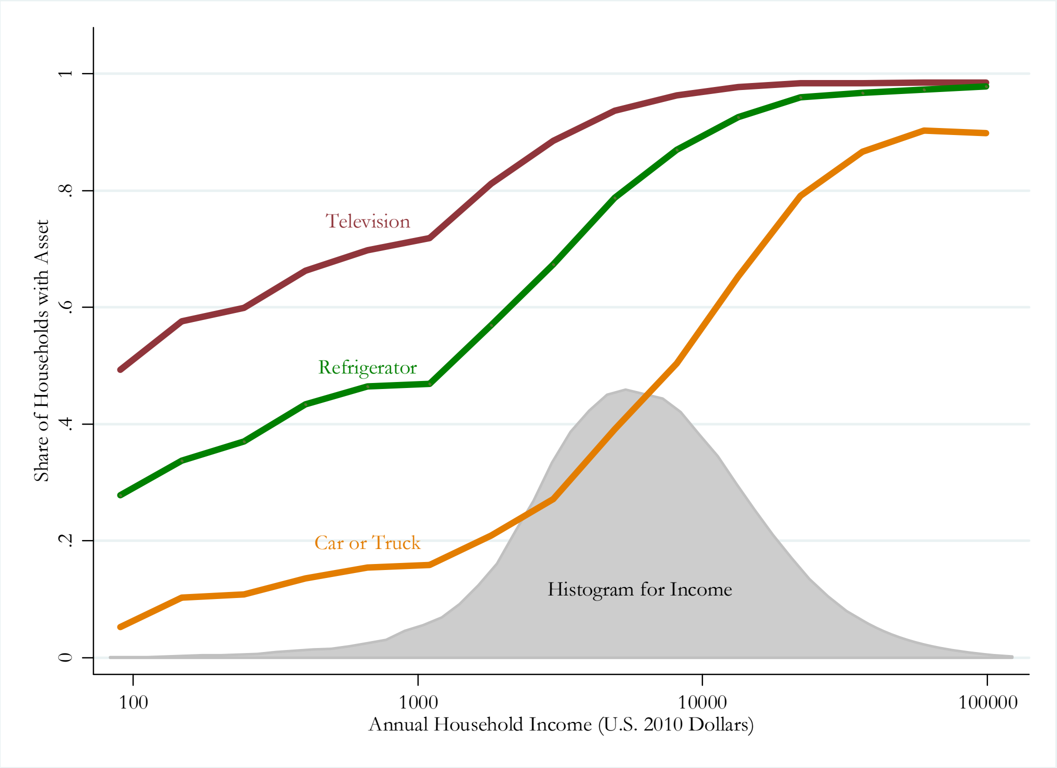


FIGURE 2a

Comparing Participants to Non-Participants: Refrigerators

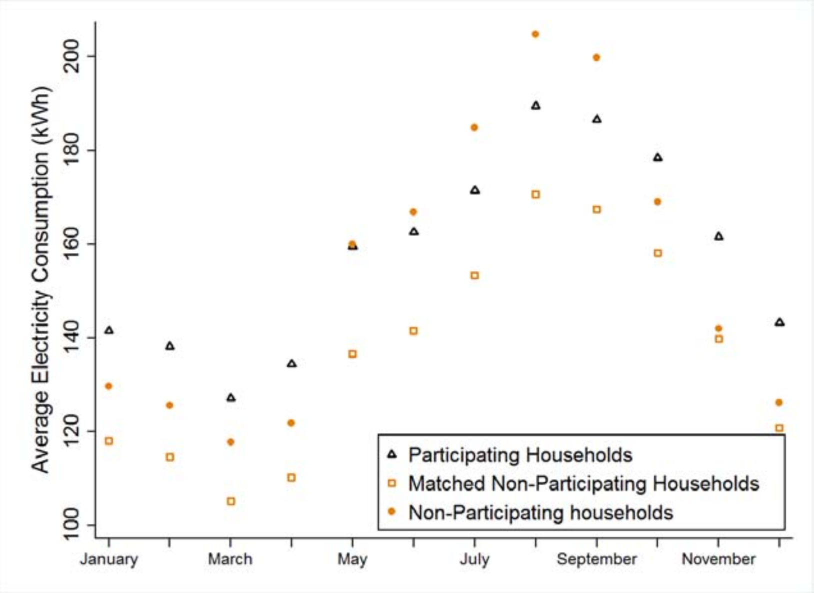
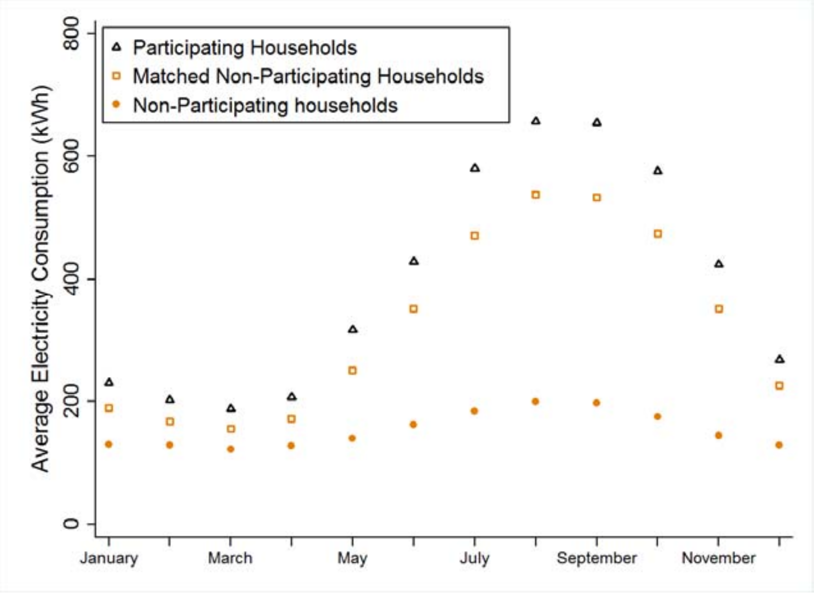


FIGURE 2b

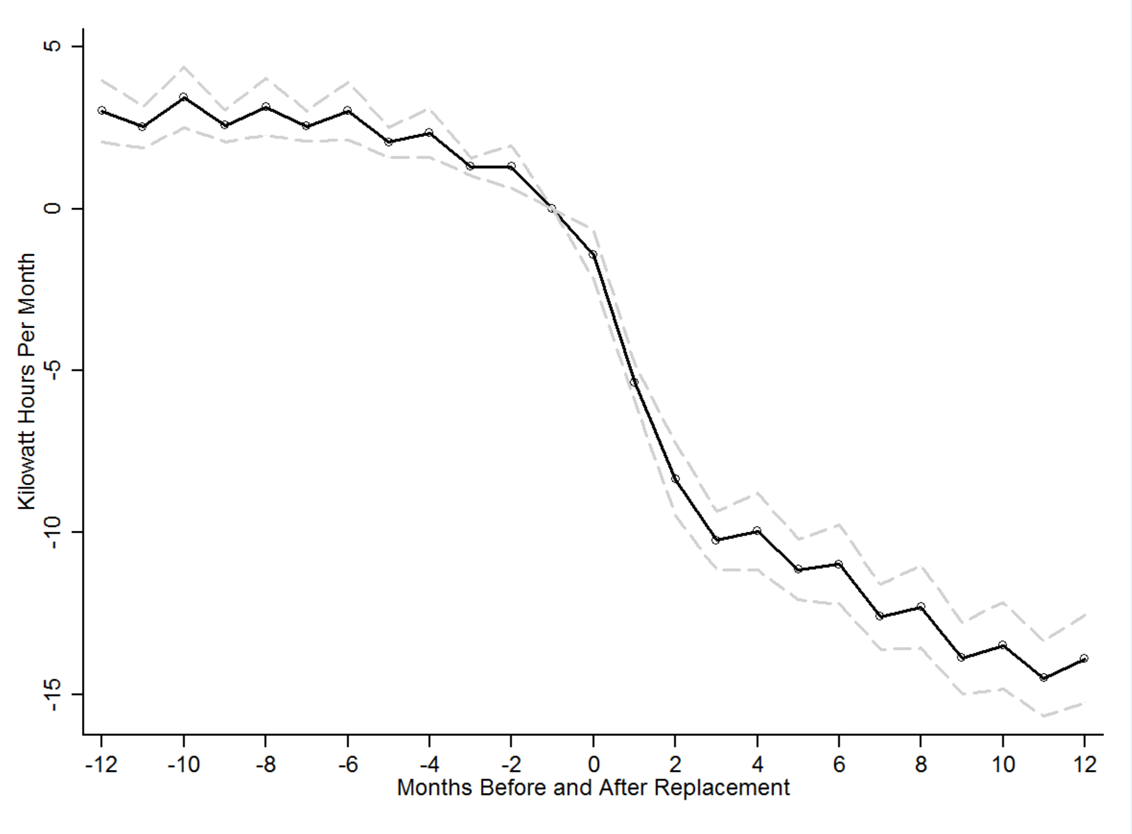
Comparing Participants to Non-Participants: Air Conditioners



Note: These figures plot average electricity consumption by calendar month for households who replaced their refrigerators and air-conditioners through the C4C program ("participating households"), non-participating households matched to these treatment households using account number information ("matched non-participating households") and all non-participating households. For all households the sample is restricted to observations from the first year of the program (May 2009-April 2010). Additionally, for treatment households the sample is limited to those who adopted after the first year of the program (May 2010-April 2011). This restriction ensures that the figure describes pre-treatment means i.e. from before households receive a new appliance.

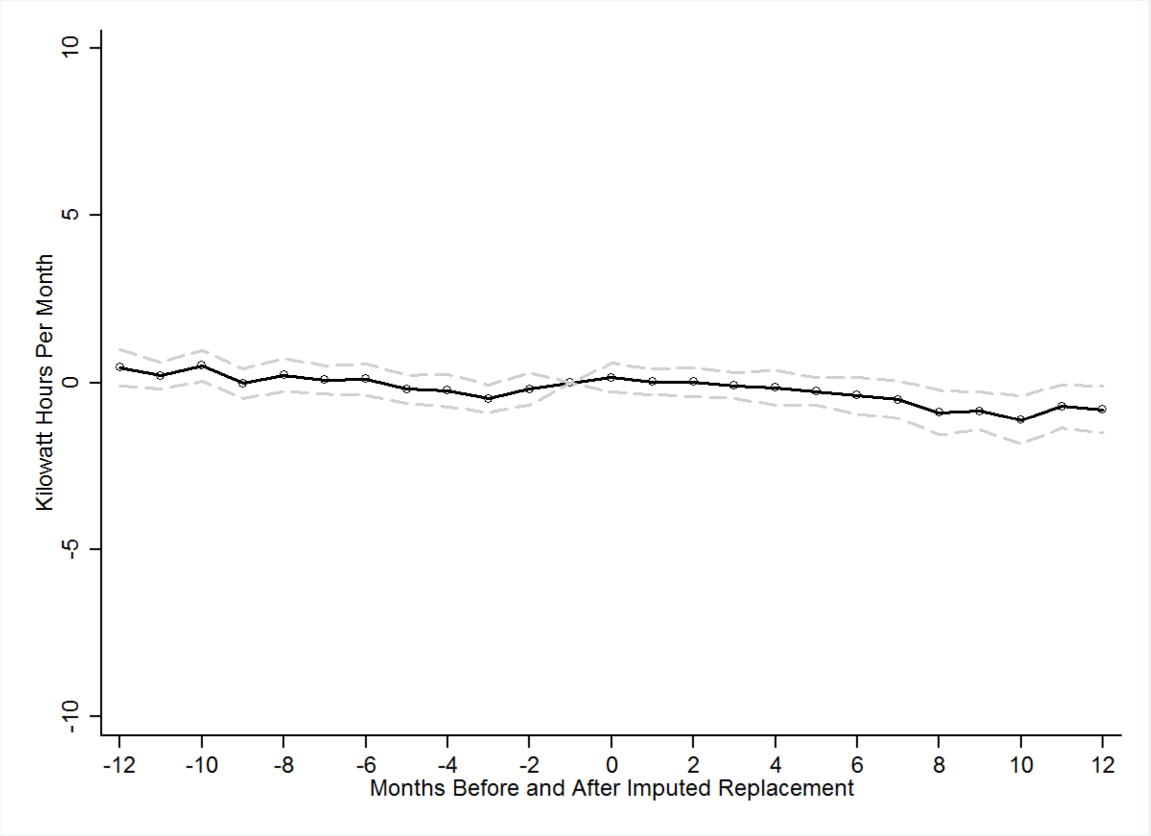
FIGURE 3

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. 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 control households matched to treatment households using account number information. The regression includes household and county by month-of-sample fixed effects. Standard errors are clustered by county.

FIGURE 4
Assessing the Validity of the Comparison Group



Note: This figure is constructed similarly to Figure 3 but using households who did not participate in *C4C*. The sample includes 858,962 non-participating households matched using account number information to households who replaced their refrigerators through the *C4C* program. Each household is assigned the replacement date for the household to which that household is matched. Time is normalized relative to this month (t=0) and the excluded category is t=-1. The regression includes household and county by month-of-sample fixed effects. Standard errors are clustered by county.

FIGURE 5A
The Effect of Refrigerator Replacement by Month of Year

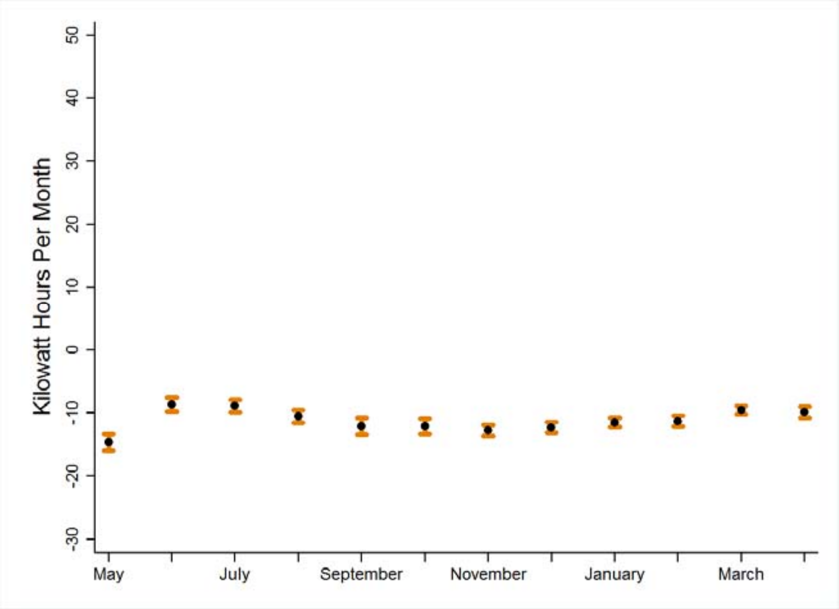
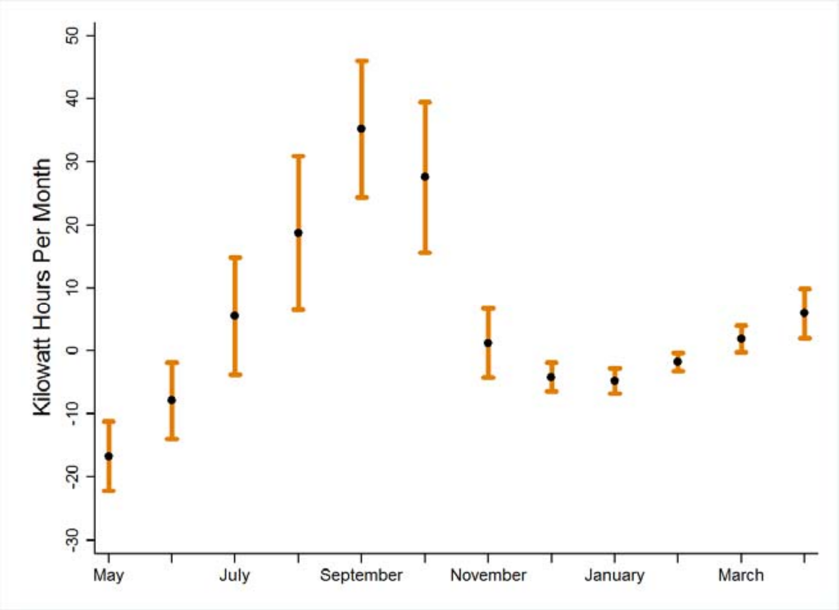


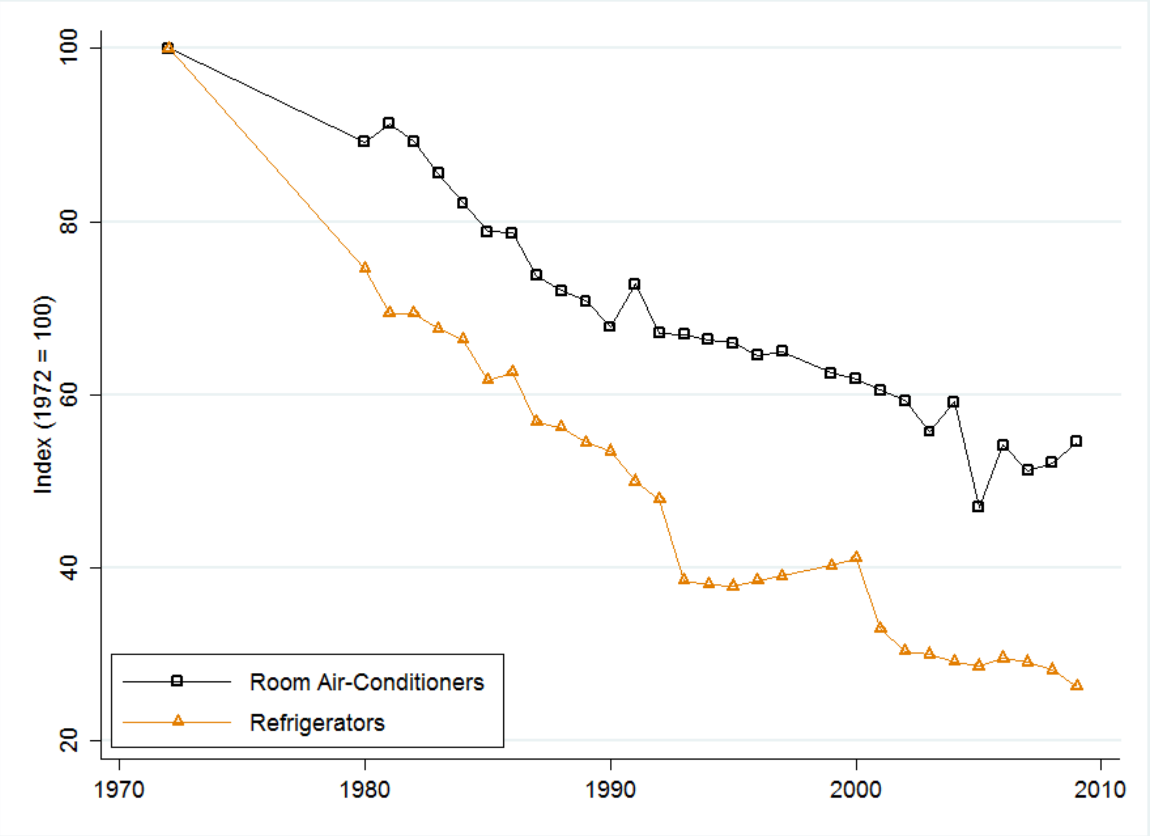
FIGURE 5B
The Effect of Air Conditioner Replacement by Month of Year



Note: Each figure plots estimated coefficients and 95th 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 matched control households. Standard errors are clustered by county.

FIGURE 6

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

	(1)	(2)	(3)	(4)	(5)	(6)
1[New Refrigerator]$_{it}$	-11.2**	-11.0**	-11.0**	-11.5**	-11.5**	-11.4**
	(0.5)	(0.4)	(0.4)	(0.4)	(0.5)	(0.5)
1[New Air Conditioner]$_{it}$	8.5*	6.6**	-0.2	-0.7	1.2	1.2
	(3.6)	(2.2)	(0.8)	(0.8)	(0.8)	(0.9)
1[New Air Conditioner]$_{it}$ x 1[Summer Months]$_{it}$			16.5**	16.6**	12.6**	14.5**
			(4.2)	(4.2)	(3.9)	(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	Yes	Yes	Yes
Including Linear Time Trend for Participants	No	No	No	Yes	No	No
Including Treatment Households Only	No	No	No	No	Yes	Yes
Dropping Month of Replacement	No	No	No	No	No	Yes
Number of Households	1,914,160	1,914,160	1,914,160	1,914,160	957,080	957,080
R^2	.92	.93	.93	.93	.97	.97

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 a sample of non-participating households matched to treatment households using account number information. Mean electricity use is 153 kilowatt hour and 395 kilowatt hour 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 by Income and Year of Replacement

	Refrigerators	Air Conditioners
A. By Mean Household Income in County		
First Tercile (Less than $5,008/year)	-8.9** (0.2) N=305,859	4.5* (2.2) N=13,203
Second Tercile ($5,008 - $7,637/year)	-11.7** (0.8) N=275,751	5.9** (1.1) N=42,175
Third Tercile (More than $7,637/year)	-12.4** (0.7) N=277,352	7.7 (4.8) N=43,226
B. By Year of Replacement		
Appliance Replaced in 2009	-10.2** (0.4) N=180,507	2.0 (3.0) N=15,267
Appliance Replaced in 2010	-11.2** (0.4) N=497,148	8.1** (2.4) N=59,499
Appliance Replaced in 2011	-5.9** (0.4) N=181,307	8.7** (2.1) 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 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 total number of households in each panel is slightly larger than the sample size in Table 3 because 486 households replaced both a refrigerator and an air-conditioner.

TABLE 5

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)	-132	79	--
Mean Annual Change in Household Expenditure Per Replacement (U.S. 2010 dollars)	-$13	$8	--
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)	-113.4	7.8	-105.6
Total Annual Change in Household Expenditures (U.S. 2010 dollars, millions)	-$10.9	$0.7	-$10.2
Total Annual Change in Carbon Dioxide Emissions (Thousands of Tons)	-66.9	4.6	-62.3
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)	$427	--	$506

Notes: This table reports estimated aggregate impacts of *C4C* for appliance replacements completed between May 2009 and April 2011. Mean annual change in electricity consumption per replacement comes from Table 3, Column (2), multiplied by 12 to reflect the annual change. 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.

APPENDIX TABLE 1
Subsidy Amounts

Consumption Category	Consumption Thresholds for Refrigerators in Kilowatt Hours Per Month (excluding summer)	Consumption Thresholds for Air Conditioners in Kilowatt Hours Per Month (summer only)	Cash Subsidy Amount	Maximum Credit Amount
1	76-175	251- 500	1,800 Pesos ($142 dollars)	3,400 Pesos ($269 dollars)
2	176-200	501-750	1,000 Pesos ($79 dollars)	4,200 Pesos ($332 dollars)
3	201-250	751-1,000	--	5,200 Pesos ($411 dollars)
4	250+	1,000+	--	8,700 Pesos ($688 dollars)

Notes: This table describes the available direct cash payments and subsidized financing available to Mexican households participating in *C4C* starting December 2009. Between April 2009 and November 2009 the consumption limits were slightly more restrictive (e.g. 76-140 in the first category) and the maximum credit amounts were slightly less generous. Consumption thresholds are defined using mean monthly consumption over the last calendar year, excluding summer months for a refrigerator replacement and excluding non-summer months for an air-conditioning replacement. Households below the first consumption category are not eligible for either form of subsidy. Dollar amounts are reported in U.S. 2010 dollars using the annual average exchange rate for that year (12.645 Pesos per dollar). In addition to the cash subsidies listed above, participants in the first three consumption categories receive a 400 Peso ($31 dollars) subsidy to cover transportation and disposal of the old appliance.

APPENDIX TABLE 2

Main Results Including Time Trend for Participants

	(1) Baseline	(2) Linear	(3) Quadratic	(4) Cubic
1[New Refrigerator]$_{it}$	-11.0**	-11.5**	-11.4**	-11.5**
	(0.4)	(0.5)	(0.5)	(0.5)
1[New Air Conditioner]$_{it}$	-0.2	-0.7	-0.5	-0.5
	(0.8)	(0.8)	(0.8)	(0.8)
1[New Air Conditioner]$_{it}$ x 1[Summer Months]$_{it}$	16.5**	16.6**	16.2**	16.1**
	(4.2)	(4.2)	(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

Notes: This table reports coefficient estimates and standard errors from four 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*. Column (2) includes an interaction between month-of-sample and an indicator for whether the household participated in *C4C*. Column (3) contains that same term as well as an interaction between month-of-sample squared and an indicator for participation. Column (4) contains both of those terms plus an interaction for month-of-sample cubed and an indicator for participation. The sample includes billing records from May 2009 through April 2011 from the complete set of households that participated in the program and a sample of non-participating households matched to treatment households using account number information. 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.

APPENDIX TABLE 3

Demographics and Appliance Saturation in Mexico, ENIGH 2000-2010

	2000 ENIGH	2002 ENIGH	2004 ENIGH	2006 ENIGH	2008 ENIGH	2010 ENIGH
Demographics:						
Total Population (in millions)	98.8	101.2	103.2	105.0	110.0	112.7
Total Number of Households (in millions)	23.7	24.5	25.6	26.5	27.4	29.1
Household Size (persons)	4.2	4.1	4.0	4.0	4.0	4.0
Number of Rooms in Home	-	3.0	4.0	4.0	4.0	4.0
Electricity and Appliance Saturation:						
Refrigerator	73.9%	76.5%	79.3%	80.4%	83.0%	83.5%
Washing Machine	-	57.1%	61.9%	65.1%	51.4%	64.4%
Television	90.0%	96.5%	98.0%	99.3%	94.0%	94.0%
Computer	-	13.7%	17.0%	20.0%	23.0%	26.7%
Electricity in the Home	99.3%	99.1%	97.3%	98.5%	97.9%	
Air Conditioning System	-	7.3%	10.0%	11.4%	11.2%	13.0%

Notes: This table describes data from the Mexican *Encuesta Nacional de Ingreso y Gasto en los Hogares (ENIGH)*, a biannual survey conducted August through November. These statistics were compiled by the authors using microdata from the long-form survey which is completed by a representative sample of Mexican households. All statistics are calculated using sampling weights. We have cross-checked total population and number of households at the national and state level against published summary statistics and the measures correspond closely. We also carefully examined, but are not reporting, expenditure information in ENIGH including, in particular, purchases of refrigerators and air conditioners. We found that the implied number of purchases in these data varied by an unreasonably large amount across years and implied a total number of purchases considerably lower than total annual purchases for those appliances according to Mexican industry sources.