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Participation Incentives, Rebound Effects and the Cost-Effectiveness of Rebates for Water-Efficient Appliances

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PARTICIPATION INCENTIVES, REBOUND EFFECTS AND THE COST-EFFECTIVENESS OF REBATES FOR WATER-EFFICIENT APPLIANCES

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Abstract:
Rebate programs for retrofitting residential properties with water efficient appliances have become a common conservation policy tool for local municipalities. Engineering estimates of water savings from rebate programs can be systematically biased because they assume all subsidized appliance replacements would not have occurred in the absence of the subsidy and because they fail to account for potential rebound effects. We partner with a water utility in North Carolina to develop a unique database that combines water use data over a three-year period for all households that participated in the utility's high efficiency toilet (HET) rebate program, water use data for a matched sample of neighbors, and a survey of rebate participants. We evaluate whether rebates are a cost-effective means for water utilities to promote water conservation accounting for both selection and rebound effects. Difference-in-differences estimators indicate no evidence of a rebound effect with HET installation. However, we find that water savings *attributable* to the rebate program are less than one-half the actual savings associated with an HET installation. Costs of saving water through toilet replacements are estimated to be between \$5.50 and \$11.00 per 1,000 gallons which compares favorably to costs of raw water through purchasing or expansion which are between \$7.00-\$11.00 per 1,000 gallons.

Keywords: rebate programs, rebound effects, water efficiency, difference-in-differences estimator

JEL Codes: Q25, Q28, H76

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PARTICIPATION INCENTIVES, REBOUND EFFECTS AND THE COST-EFFECTIVENESS OF REBATES FOR WATER-EFFICIENT APPLIANCES

1. Introduction

Rebate programs for retrofitting residential properties with water efficient appliances have become a common conservation policy tool for local municipalities. While no comprehensive list is available, the U.S. Environmental Protection Agency lists over 100 rebate programs across the country, the vast majority of which focus on rebates for installation of high efficiency toilets (HETs).[2] In the U.S., toilets are the largest single source of indoor water use, accounting for almost 30% of a household's indoor water use on average.[3] Although rebate programs for HET installation are offered to millions of households across the U.S.,[4] we are unaware of attempts to quantify their effectiveness as a water conservation tool for utilities.

Engineering estimates suggest significant water savings are possible with bathroom retrofits. Replacing a pre-1990 model toilet with an HET can reduce water usage for a family of four by between 16,000 and 42,000 gallons per year, depending on the age of the toilet replaced. However, there are two reasons rebate programs may not provide utility managers with these expected water savings. The first is that there may be rebound effects associated with the installation of water-efficient appliances. Rebound effects refer to the potential increased use of the resource that results when there is a decreased cost of the services provided by the high-efficiency appliance (e.g., decreasing the cost of washing clothes will lead to more loads being washed more frequently). Because an HET reduces the costs of waste removal, it is possible that

[2] Rebate programs are available at: http://www.epa.gov/WaterSense/rebate_finder_saving_money_water.html
[3] U.S. Environmental Protection Agency, "Indoor Water Use in the U.S.," available at: http://www.epa.gov/WaterSense/docs/ws_indoor508.pdf, last accessed October 4, 2011.
[4] For example, the California Water Service Company alone, which includes 21 districts serving over 460,000 customers, lists a rebate program for high-efficiency toilets in all 21 of its districts. See http://www.calwater.com/conservation/rebates_residential.php, last accessed October 4, 2011.

rebound effects as typically referred to in the literature may exist through this avenue. However, with HETs, we expect the main avenue by which rebound effects might occur is if households are unsatisfied with waste removal capabilities of the toilets and flush more than once and/or use other bathrooms (without HETs installed) in the home as a result. In all instances, however, the indication is that *ex-post* calculations of water savings from HET installations will be lower than engineering estimates would suggest.

The second reason rebates may not be effective water management tools is that the rebate itself may not induce the retrofit. To the degree that a rebate is given to a household *after* their decision to replace an old appliance with a high-efficiency one, the rebate represents a windfall gain to the household rather than an expenditure on demand-side management of water resources. We are not aware of any evidence indicating the degree to which rebates have induced the household to replace old appliances (toilet or other) that would not have been replaced otherwise.

Our research seeks to determine whether rebate programs are a cost-effective means for water utilities to promote water conservation by *(i)* determining the degree to which rebound effects exist with HET installation and *(ii)* determining the degree to which rebates were the inducement for households to replace their old toilets. We partner with a water utility in North Carolina to develop a unique database of 683 households that participated in a rebate program for HET retrofits that combines three-and-a-half years of household water use data with a survey to determine the household's motivation for replacing their old toilets. In addition, we gather monthly water-use data for a matched sample of 25,100 households neighboring rebate households who did not participate in the program. This unique data allows us to explore both the existence and magnitude of potential rebound effects with difference-in-difference modeling of household water use pre- and post-HET installation. It also allows us to examine the degree to which the rebates induced households to replace their old toilets and thus can be credited with the resulting water conservation.

Our results provide no evidence of a rebound effect with HET installation and suggest that the replacement of an older toilet with an HET appears to guarantee substantial reductions in household water use. However, the survey indicates that the rebate appeared to be a pure windfall gain for 47% of our sample. In other words, these households would have replaced their old toilet with an HET even if the rebate were not available. Overall, we find that water savings *attributable* to the rebate program are less than one-half the actual savings associated with an HET installation. As a result, when considering only the water savings attributable to the rebate program, estimates of the program's cost-effectiveness are severely diminished. We estimate the cost per thousand gallons conserved through rebate expenditures to be between $2.50 and $5.00 per 1,000 gallons conserved when attributing all water conservation to the rebate. However, when considering only the water conservation that would not have occurred except for the rebate, the cost per thousand dollars of the program increases by approximately 125% to between $5.50 and $11.00 per 1,000 gallons.

The remainder of this paper is as follows. First, in Section 2 we describe the rebate program examined in this study, the survey that was administered to households receiving a rebate, and the water-use data available for our analysis. Section 3 estimates the rebound effect by first calculating the engineering estimate of water conservation associated with HET installations in our sample and then comparing this estimate to those arising from the observational data on water use pre- and post-HET installation. Section 4 combines our preferred estimate of water conservation associated with HET installation with survey data on the incentive effects of the rebate program. In this section, we develop cost-effectiveness measures that are inclusive of both behavioral responses to the toilets (e.g., include rebound effects) and to the rebate program itself. Conclusions and suggestions for increasing the cost-effectiveness of rebate programs follow in Section 5.

2. Program Background and Data

To determine the impact of HET installation on water-use, we employ a unique database of 1,195 HET installations in 683 households living in the Town of Cary, North Carolina. Cary is adjacent to Raleigh, the State capital, and has a population of over 130,000 that is served by a single water utility owned by the township. Cary introduced its High Efficiency Toilet Retrofit Rebate program in June 2008. Our data are from the first two years of the program.

During the first 13 months of the program (June 1, 2008 to June 30, 2009), Cary offered a \$150 rebate per toilet for water customers who replaced toilets that use 3.5 gallons or more per flush (gpf) with WaterSense labeled high efficiency toilets that use 1.28 gpf in their homes.[5] Rebates were limited to three per residence and homeowners had to submit original receipt(s) for the HET toilets with purchase dates on or after June 3, 2008. During the second year of the program, the Town reduced the rebate amount to \$100 for up to two toilets. Site visits were initially scheduled to ensure toilets had been installed, but after 100% compliance rates were observed, the Town simply recorded the installation date of each toilet for the remainder of the program.

Cary budgeted an amount sufficient to replace 592 toilets in the first year and 790 toilets in the second year. In the first year, 305 households received rebates for 592 toilets and in the

[5] The rebate program also included businesses, however only two rebates were distributed to commercial customers which we do not include in our analysis. Furthermore, 10% of the rebates offered were reserved for customers who had newer 1.6gpf toilets.

second year, 378 households received rebates for 603 toilets, indicating that the rebate funds were not fully utilized in the second year.

Survey of Rebate Program Participants

To understand how the rebate affected households' decisions to replace toilets, a survey was mailed to all 305 residential customers receiving rebates during the first year of the program. The surveys were mailed on June 17, 2010 and of the 305 surveys mailed, six were undeliverable due to moves with no forwarding addresses.[6] Of the 299 deliverable surveys, 245 were returned for a response rate of 80.3%. Of these 245 surveys, one was not usable because the ID number had been marked through and thus could not be matched back to utility records, leaving 244 usable surveys. These 244 survey respondents reported that they installed 527 HET toilets. Of the toilets installed, 523 received a rebate. Thus, our survey respondents cover 88% of the 592 toilets that were available to receive a rebate in first year of the program.

Table 1 summarizes the demographic and housing characteristics of the survey respondents. As indicated in Table 1, the rebate recipients are highly educated (88% have a college degree) and have household incomes well above the national averages. These statistics are, however, similar to the general demographics of Cary. As compared to the general citizenry of Cary, rebate participants are somewhat older, more educated, and have fewer minorities represented. These differences are not surprising given rebate participants must be homeowners and the demographics reported for the Town of Cary reflect all adult citizens of the town.

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[6] Following Dillman (1978), two weeks after the initial survey was mailed, a reminder post-card was mailed to those who had not yet returned the survey. Three weeks after the reminder post-card was mailed, a second blank survey with a reminder cover-letter was mailed to those who still had not returned the survey. The cover letter indicated that it was the last time they would be contacted by the researchers. The cover letters and original survey instrument are contained in Appendix A. Note, the survey in Appendix A is formatted for printing on 8.5x11 inch paper, while the original survey was produced as a 7x8.5 inch booklet.

The survey also collected information on a few key features of the rebate participant's home. The average age of a home that received a rebate is older than for the general housing stock in Cary. Individuals who received a rebate also have lived in their home slightly longer than the average for the Town. Again, neither of these differences is surprising given that only older toilets (pre-1990) were eligible for rebates and Cary experienced extraordinary growth in home starts during the 1990s and 2000s. The mean and median number of bathrooms per home is three, indicating that for a substantial portion of surveyed households (82%), the three rebates offered in the first year of the program could replace all toilets in the house. In the second year of the program, the Town reduced the number of rebates per household to two, which would cover all toilets in the home for only 17% of households (assuming the second year's program participants had home structures similar to the first year's participants).

Household Billing Data

To explore the potential for rebound effects associated with HET installations, we obtain actual water use data for each household participating in the first two years of the rebate program. Table 2 summarizes the installations by the rebate households. Monthly billing data for all 683 households, covering 1,195 HET installations, was obtained from the water utility for the months January 1, 2007 through September 1, 2010. There was an average of 1.74 HET installations per household. Most households (49%) received a rebate for two HETs, while 38% of households received a rebate for only one HET. The remaining 13% received a rebate for three HET installations. Table 2 also indicates the distribution of HET installations across time. During the first year of the program (June 1, 2008 to July 1, 2009) most rebates were given out in the first six months. In the second year of the program, the rebates were spaced more evenly throughout the time frame.

The difference-in-difference analysis we employ compares the water use of rebate households over time to similar non-rebate households over the same period of time. To this end, billing data was also obtained for a matched set of "neighbors" for each rebate program participant. Ideally, matched households would be similar in terms of the number of people living in the house, the number of bathrooms, and their general outdoor and indoor water use habits. However, this type of information is not available. Thus, we matched the set of HET households to control households who have similar property characteristics in terms of the size of their home and property. We consider a household to be a match for a rebate household if:

(1) the parcel lies within a 0.5 mile radius of the rebate house;

(2) the parcel is the exact same land class (e.g., single-family residential);

(3) the parcel's acreage is +/- 0.1 acres of the rebate home's acreage;

(4) the home has a square footage that is +/- 350 square feet of the rebate house; and

(5) the "matched neighbor" is not another HET house.

There were 25,100 parcels that fit the criteria above, or an average of 37 neighbors to each rebate household. The maximum number of matched neighbors to a single rebate household was 321 and the minimum was one household.

Table 3 presents the average monthly water consumption for our sample of households. Over the entire sample period the mean monthly water use was 4,538 per month. Prior to the rebate program's implementation the mean use was 4,740 gallons per month and it was 4,409 gallons per month after the program's implementation, a difference of about 330 gallons per month. Figure 1 presents the mean monthly water consumption for rebate recipients and their matched neighbors over the 44-month study period. The apparent divergence in mean monthly water use of the rebate households from their matched neighbors after the rebate program begins is striking. Figure 1 also highlights the length of monthly data we have available pre- and post-program to help identify the effects of HET installation on monthly water use.

The peak in water consumption during summer 2007 (see Figure 1) was due to a significant drought in the region. The water use of rebate households and matched neighbors increases dramatically during this drought period, but in a similar manner. In Table 3, we also report the mean monthly water use for our sample excluding summer months. As indicated in Table 3, the mean monthly water use for our entire sample decreases 462 gallons per month pre-rebate program from 4,740 to 4,278 gallons per month, and the variability in the data decreases somewhat as evidenced by the smaller ratio of mean monthly use to its standard deviation. The same is true in the post-program months when summer water use is excluded.

Table 3 also reports the mean monthly water use by whether or not a household participated in the rebate program. The striking similarity of average water use of rebate households to non-rebate households prior to the implementation of the rebate program is also apparent in these summary statistics. The mean monthly water use (including or excluding summer months) is identical between the two samples prior to the rebate program's beginning and is smaller for the rebate household's post-program. The mean monthly water use is 366 gallons less per month for rebate households across the entire time period and 389 gallons per month less if we exclude summer water usage from the calculation. Of course, due to the large variability of water use across households, the mean monthly use for rebate and non-rebate households are not statistically different. To determine if there is indeed a statistically detectable difference in water use across the two groups, we now turn to our micro-level difference-in-difference analysis.

3. Estimating the Rebound Effect

A relatively large literature has evolved that seeks to estimate the rebound effects associated with energy efficiency. Greening, et al. (2000) summarize 75 studies and find that the literature varies widely on the size of rebound effects, depending on the fuel and service being considered. They suggest that the literature implies a 10-30% rebound effect for residential heating, 10-40% for hot water heaters, and 5-20% for lighting. These magnitudes imply that technological improvements could be 95% effective (for lighting) or as little as 60% effective (for hot water heaters) in reducing energy consumption. There is much less evidence on the rebound effects associated with water efficiency. Recently, Davis (2010) examined changes in behavior associated with installation of high-efficiency clothes washers, which can use an average of 48% less energy and 41% less water than standard washers. Davis finds a small rebound effect, suggesting that the average household increases their utilization of clothes washing machines by about 5.6% even though it costs about 40% less per cycle to run them.

Past studies focus on price effects as the mechanism by which rebound effects occur, and generally assume the quality of the services provided by the high-efficiency appliance is held constant. This makes sense for most energy retrofits such as air-conditioners and heaters where the new items are designed to deliver a specific temperature at lower cost/energy use. In our application it is likely that rebound effects would arise primarily through changes in service quality, i.e., if the HET does not remove waste well. Our approach estimates an effect that is inclusive of both price and service quality effects.[7] To estimate the rebound effect, we first compute an engineering estimate of the mean change in water use for our sample that

[7] Price-induced rebound effects can occur as well through two avenues with an HET installation. First, the decreased water volume per flush reduces the cost of waste removal. Second, the Town of Cary has increasing block pricing for water services. If the HET installation results in household water consumption falling below a threshold, the household may fall into a lower-price block, and thus have a lower marginal price for water consumed further reinforcing the price effect.

accompanies an HET installation. This estimate is then compared to the observed change in water use from our difference-in-difference analysis.

Engineering Estimates of Water Savings

On a per-flush basis, an engineering estimate of the water savings is simply the difference in gallons per flush (gpf) used by the original toilet and the installed HET. We are able to precisely estimate the water savings per flush because the Town of Cary collected information on the gpf of the toilet that was replaced and the new HET.[8] However, our observational data (monthly water use) is measured per household, per month. To compute an engineering estimate of water reduction that is comparable to the observational data, we use information gathered in our survey to determine the frequency with which each HET is flushed per month.

To compute the expected flushes per month, we assume that households are home 50 weeks per year and thus at home an average of 29 days per month. Meyer, et al. (1999) report that on average there are 5.1 flushes per residential toilet per person in the household (this includes an average over those who work at home and those who do not).[9] We also assume each toilet in the house is used equally so that the total number of flushes per day per toilet is proportional to the number of people divided by total number of toilets. Our survey data provides information on the number of individuals and the number of bathrooms in the household. Thus our estimates of engineering savings are based on the rebate participants from the first year of the program only.

The daily engineering savings (*ESavings*) associated with replacing toilet n in household i is calculated as follows:

[8] Note, the maximum gpf for an HET is 1.28 gpf. However, some HETs are dual-flush and use less water on average than 1.28 gpf. For the dual flush models, we use an estimated average of 0.736 gpf for these models.
[9] Estimate provided by Meyer et al., *Residential End Uses of Water,* (Denver: AWWA Research Foundation, 1999), p. 95.

$$Esavings_{ni} = \frac{N_i * 5.1}{T_i}(gpf_{ni} - gpf_{HET}) \quad (1)$$

where gpf_{ni} is the gallons per flush used by the n^{th} original toilet; gpf_{HET} is the gallons per flush used by the replacement HET; N_i is the number of people in the household; T_i is the total number of toilets (HET or not) present in the house;[10] and flushes per day are assumed to be 5.1. Equation (1) is multiplied by 29 days to estimate the monthly water savings, or 351 days to estimate yearly water savings.

There are 469 HETs that were replaced during the first year of the program for which we have complete survey information to calculate equation (1). For these 469 HETs, the mean savings per HET installed is 366 gallons per month or 4,392 gallons per year. The smallest estimated engineering savings for a rebate was 15 gallons/month associated with a one-person household that received a rebate to replace a 1.6 gpf toilet with a 1.28 HET toilet. The largest estimated engineering savings was 1,361 gallons/month associated with a five-person household that replaced a 7.0 gpf toilet with an HET. The standard deviation on our monthly mean water savings is 233 gallons per month.

Difference-in-Difference Estimates of Water Savings

As discussed earlier, it could be the case that the engineering estimates do not reflect actual water savings from toilet installation due to behavioral responses of the household. For instance, if the toilet does not function to the household's satisfaction, they may flush it more than one time per use, or may choose to use it less often than other toilets (if they do not replace all toilets with an HET). In this case, the engineering savings we have constructed would overestimate the savings associate with an HET installation. Conversely, a household may

[10] This component of equation (1) assumes that flushes are randomly distributed across toilets present in the house throughout the day. In other words, we assume individuals do not actively choose to use the HET toilet in lieu of others (or vice-versa).

choose to use an HET toilet over non-HET toilets (if they did not replace all their toilets) to conserve more water. We would underestimate the savings attributable to an HET installation in this case.

In this section, we estimate the actual water savings attributable to a subsidized HET installation. The ideal estimate would involve comparing water usage in two identical households, one with a subsidized HET installation and one without. If everything else about the households was the same (for example, number of people, hours in the home, number of toilets, other water-using fixtures etc) then differences in water usage at the HET household could reasonably contributed to the toilet as it is actually used.

Of course, this experimental ideal does not exist. Thus, we construct an approximation to this ideal using observational data. This requires a combination of matching on observable household characteristics and differences-in-differences to adjust for time-invariant household unobservables. As noted earlier, we construct a set of 25,100 matched households who have similar property characteristics in terms of the size of their home and property. Of course, there may be other unobservable differences among rebate and non-rebate households that are correlated with water use in ways that are unrelated to HET adoption. As long as these unobservable differences are time-invariant we can address them using a difference-in-differences (DID) model. The basic DID estimator is given by:

$$Water_{it} = \beta_1 HET1_i + \beta_2 HET2_i + \beta_3 HET3_i + \gamma_t + \delta_1 HET1_i * D1_{it} + \delta_2 HET2_i * D2_{it} + \delta_3 HET3_i * D3_{it} + \varepsilon_{it} \quad (2)$$

where *Water*, is the water use (in gallons) of household *i* in time *t*; *HET1*, *HET2*, and *HET3*, are dummy variables equal to one if the household installed and received a rebate for one, two or three HETs, respectively; γ_t are month-year dummy variables. The final three terms are constructed by interacting the household HET type (1 toilet, 2 toilets or 3 toilets) with a month-specific treatment indicator that takes a value of 1 after the household installs their first, second, or third HET, respectively. For example, if household i installs their first HET toilet in month 22, their second HET toilet in month 24, and their third HET toilet in month 26, $D1_{it}$ would equal 1 for months 22 and 23, $D2_{it}$ would equal 1 for months 24 and 25 and $D3_{it}$ would equal 1 for months greater than or equal to 26. The coefficients δ_1, δ_2, and δ_3 then provide the difference-in-differences estimates for water savings from installation of 1, 2, or 3 HET toilets, respectively, relative to a household that has installed no HET toilets.

We estimate equation (2) with two different assumptions on the structure of the error term. The first is simply using robust standard errors allowing for heteroskedasticity. However, given that the matched sample was constructed by neighborhood, we consider the possibility that observations, while independent across neighborhoods, may not be independent within neighborhoods. Each control observations is assigned to at least one treatment observation which we define as a "rebate group" (i.e., the set of homes assigned to a particular household that received a rebate). To allow for the possibility of correlation within rebate group we estimate equation (2) with standard errors clustered by rebate group.

As another method for addressing possible correlations about households in the same rebate group, we modify equation to (2) to include rebate group dummy variables, D_{ig}:

$$Water_{igt} = \beta_1 HET1_i + \beta_2 HET2_i + \beta_3 HET3_i + \gamma_t + \delta_1 HET1_i * D1_{it} + \delta_2 HET2_i * D2_{it} + \delta_3 HET3_i * D3_{it} + \theta_g + \varepsilon_{it} \quad (3)$$

The differences-in-difference coefficients now represent water savings from HET installation relative to control households in the same rebate group. Equation (3) is estimated with robust standard errors and standard errors clustered by household identifier (meter).

All models are estimated on a panel of 683 rebate households, 112,191 matched observations (including duplicates for parcels that served as a match for more than one rebate household), and 44 months of billing data for a total of 4,579,439 observations.[11]

The results for all DID estimations are in Table 4. Results from estimation of equation (2) are in the first two columns. Installation of a single HET toilet saves 354.34 gallons per month relative to no toilets. The difference between two HET toilets and no HET toilets is 767.45 gallons per month and the difference between three HET toilets and no HET toilets is 913.09 gallons per month. These estimates are statistically significant at the 1% level even when standard errors are clustered at the HET group level. The first and second toilet appear to each result in about the same water use reductions. The third toilet offers somewhat less additional savings than the first two toilets. The weighted average water conservation implied by these results is 362 gallons per month per HET, with a 95% confidence interval of 242 to 483 gallons per month.

The results from equation (3) can be found in the last two columns of Table 4. When HET group dummy variables are directly included in the model the estimates of water savings are largely unchanged. Estimated savings from one toilet are 313.21 gallons per month; from two toilets the savings is 666.58 gallons per month or 333 gallons per toilet, per month. Finally, for three toilets the savings is 983.45 gallons per month or 328 gallons per toilet, per month. Across households with different numbers of HETs installed, the results in this model are remarkably stable, indicating a per-toilet water savings that is nearly identical for the first, second and third toilet. The weighted average water reduced implied by the model in equation (3) is 325 gallons per month, with a 95% confidence interval of 214 to 436 gallons per month.

[11] Not all matched households had complete billing data for al 44 months, and so we have an unbalanced panel.

The DID results are remarkably similar to the engineering estimate of water savings, which was 366 gallons per month. This indicates that for high-efficiency toilets there does not appear to be a significant rebound effect. People do not appear to be using the HET toilets more or flushing them more frequently. Of course, we recognize that the engineering estimate is based on assumptions regarding the amount to which a particular toilet is used in the household. If our assumptions have artificially inflated the engineering estimate of water savings, it could be the case that we are making a Type II error. In other words, we may fail to reject the null hypothesis that there is no rebound effect (i.e., that engineering and behavioral estimates of water savings are identical), when it is indeed false. We find it unlikely that our assumptions could be so wrong as to imply we have made a Type II error. We have excellent information on the gpf of the old and new toilets, the number of toilets in the house, and the number of individuals living in the home. Thus our main source of error in the engineering estimates is the number of times a person living in the household flushes a toilet. We assumed 5.1 times per day as indicated by Meyer et al. (1999). The correct number of flushes would have to decrease to one per day in order for us to have made a Type II error – a rate that we find unrealistically low.[12]

Recall from Table 3 that the average indoor water use for our full sample of homes (as proxied by water use in non-summer months) prior to the rebate program, is 4,278 gallons per month. Our preferred estimate of water savings associated with an HET installation is 325 gallons per month, as estimated with the model including household fixed-effects (equation 3).

[12] If we assume one flush per day, the engineering estimate of the mean monthly savings is 72 gallons per month with a standard deviation of 46 gallons. The upper-bound of the 95% confidence interval for the engineering estimate (161 gallons) falls outside the lower-bound of the lowest 95% confidence interval from the DID estimates (214 gallons). For comparison, if we assume two flushes per day, the engineering estimate of the mean monthly savings is 144 gallons per month with a standard deviation of 91 gallons. Here the 95% confidence intervals for the engineering and DID estimates have significant overlap. The 95% confidence interval for the engineering estimate is -35 to 322 gallons/month and 213 to 436 gallons/month for the DID estimates. The engineering estimate 95% confidence interval nearly contains the mean estimate of water savings from the DID models in this case.

Thus, our results indicate that household water use declines 7.6% per month, per high-efficiency toilet installed, on average.

4. Rebate-Induced Participation and Cost-Effectiveness

The cost-effectiveness of rebate programs hinges on the process by which households select into the rebate program. In this section, we consider the motivation of the household to replace their toilet. There are three ways the rebate program could influence a household's toilet replacement decision. First, the household may not have been planning to replace their old toilet, and the rebate program induced them to do so. In this instance, the water savings implied by the toilet replacement is attributable to the rebate. In the second case, the household may have been planning to replace their old toilet with a new, but not high-efficiency toilet and the rebate program induced them to move to an HET. For this group, the water savings that can be attributed to the rebate is 0.32 gpf, which is the difference between the gpf of a new, but not efficient toilet (1.6 gpf) and an HET (1.28 gpf).[13] Lastly, there may have been households who were planning to replace their old toilet with an HET, regardless of the rebate program. In this case, the rebate was simply a windfall gain to the household and the municipality received no additional water savings as a result of the rebate expenditure.

The survey asks rebate recipients a series of questions about the basis for their decision to replace *each* toilet, and thus, we can determine whether each rebate *resulted in* a complete, partial, or no change in water consumption. The portion of the survey containing these questions is presented in Figure 2. Table 5 summarizes the responses. There were 240 households that provided complete information for 485 HET installations. Among these households, 80% knew

[13] Beginning in 1991, all toilets had to use no more than 1.6 gpf, which remains the industry standard for new, non-efficient, model toilets.

about the rebate program prior to deciding to replace their old toilet and 83% replaced only their toilet (i.e., the replacement was not part of a larger renovation). At first blush, these two statistics might lead one to assume that most of the HET installations occurred as a result of the rebates. However, our survey results indicate that only 33% of old toilets were replaced because of the rebate. Perhaps surprisingly, 47% of rebates were given to households that would have installed an HET anyway. Lastly, 19% of the rebates went to households who had planned to replace their toilet with a new, but not high-efficiency toilet, but the rebate induced them to move to an HET.

Based on the three groups of households characterized above, we now compute the water savings (*WS*) per flush that is attributable to the rebate program as:

Group 1 – rebate induced replacement of the old toilet and $WS_1 = (gpf_0 - gpf_{HET})$;

Group 2 – rebate induced move from new 1.6 gpf toilet to HET and $WS_2 = (1.6 - gpf_{HET})$;

Group 3 – rebate was a pure windfall gain to the household and $WS_3 = 0$.

The daily water savings, per HET replacement, that is directly attributable to the rebate program (*Rsavings*) is then calculated as:

$$Rsavings_{ni} = \frac{N_i * 5.1}{T_i}\left(WS_{nji}\right) \quad (4)$$

where all is defined as in equation (1) except WS_{nji} is the water savings for the nth toilet in household *i* as determined by whether or not the toilet replacement falls into Group *j*=1, 2, or 3 as defined above.

Equation (4) is computed for each HET toilet for which we had information on the household's motivation for installing an HET and multiplied by 29 days to compute estimated monthly rebate-induced water savings. The average water savings associated with the 485 rebates for which we have sufficient information to calculate equation (4) is 146 gallons per month or 1,752 gallons per year. Thus, the *rebate-induced* water savings is 40-45% of the actual water savings estimated by the DID models, indicating that much of the water savings would have occurred even in the absence of the subsidy program.

As indicated earlier, while there are many rebate or direct subsidy programs for a variety of water-efficient appliances, there are no evaluative studies such as ours to determine the degree to which the rebates resulted in water use reductions that would not have occurred otherwise. There have been recent examination of rebate programs in other markets, and in particular for hybrid vehicle adoption. Income tax, sales tax, and direct-cash rebates for hybrid vehicle purchases have been analyzed in the U.S. and Canada and results indicate that rebates induced as little as 6 to 32 percent of the purchases of hybrid vehicles (Chandra, et al., 2010; Berenstein and Li, 2011, Ghallager and Muehlegger, 2011). The upper bound of the estimated impact of rebates on hybrid vehicle adoptions is near our lower-bound estimates of HET adoption due to the rebate, but comparing these two types of programs is difficult. A new car purchase is obviously a much larger proportion of household income, and the rebate on a new automobile is a much smaller proportion of the total cost (usually 10% or less). New high-efficiency toilets have come down in price over the years and the Town of Cary rebate ($100-$150) was sufficient to cover 100% of the purchase price if one chose a model at the lowest-end of the price spectrum.

Cost-effectiveness

To determine the cost-effectiveness of the first year of the program, we compute an annualized cost-per-gallon saved and compare this to other actions the Town might have considered. The cost effectiveness measures vary according to two assumptions. The first assumption is the number of gallons conserved by the rebate program. We first assume that the gallons saved by the rebate program is equivalent to the observed reductions in water use estimated by our preferred DID in equation (3), or 325 gallons per month or 3,900 gallons per year, per HET installed. Alternatively, we assume that the gallons saved by the rebate program are only those that can be attributed to the rebate, or 146 gallons per month or 1,752 gallons per year, per HET installed.

The second assumption that drives variations in the cost-effectiveness estimates relates to what would have happened to an older toilet had the rebate program not been in effect. Water savings accrue to the water utility over time, although the rebate expenditure is a one-time, up-front payment. To determine an annual cost-effectiveness measure, we have to know the period over which the water savings occur due to the rebate. One might assume that the conservation associated with an HET installation lasts for the life of the toilet. However, this assumes that the old toilet would have never been replaced at some future point in time. This seems unrealistic. We thus compute the cost-effectiveness under a variety of assumptions about how long it would have taken the old toilet to be replaced had the rebate program not existed. Specifically, we assume 5, 10, 15 and 30 years.

To convert the Town's rebate expenditures from an up-front payment to an equivalent annuity payment, we use a 5% interest rate.[14] The cost-effectiveness of the rebate program is then computed as the annual annuity cost divided by the annual gallons saved. Table 6 presents estimates of the cost-effectiveness implied by the HET installations and the rebate program. In the first year of the rebate program, the Town of Cary spent \$150 per HET rebate or \$88,800 for 592 toilet replacements and in the second year, they spent \$100 per rebate or \$60,300 for 603 toilet replacements. Column three in Table 5 presents the cost-effectiveness estimates when we attribute all the changes in water use estimated by the DID model to the rebate program. In this scenario, the cost-effectiveness of the rebate program varies from as little as \$1.67 when the

[14] The Town of Cary typically uses 5% as its cost of capital when analyzing potential projects.

rebate cost is $100 and the assumed life of the old toilet in absence of the rebate program is 30 years to nearly $9 per 1,000 gallons if the rebate is $150 and the assumed life of the old toilet is only 5 years. As indicated in the last column of Table 6, the cost-effectiveness of the rebate program increases by 123% when we only attribute rebate-induced water savings to the rebate expenditures, and ranges from approximately $4.00 to $20.00, depending on the rebate cost and the assumed life of the old toilet in absence of the rebate program.

It should also be noted that the cost-effectiveness measures for year 2 of the program are likely an underestimate of the actual cost. Recall, we only had survey data available for the first year of the program. As such, our estimates of the rebate-induced water savings in the second year rely on the assumption that at $100 per rebate, the same proportion of *Group 1*, *Group 2*, and *Group 3* households would have been observed as when the rebate was $150. While this could be the case, we find it more likely that when the rebate is smaller, it is less likely that it will fully incentivize a toilet replacement that would not have occurred otherwise. Thus, we expect that smaller rebates would shift the distribution of households away from *Group 1* toward *Group 2* and *Group 3*, decreasing the amount of water savings that could be attributed to the rebate. Unfortunately, we cannot address this important empirical question because we only have survey data available for the first year of the program.

The variation in cost-effectiveness within a program year is driven by the assumption about how long the old toilet would have remained in place without the rebate program, on average. While we have no evidence to draw upon, we consider 10-15 years a reasonable mid-point estimate. With this in mind, our comparative discussion on cost-effectiveness measures of approximately $8.00 to $11.00 per 1,000 gallons for the first year of the program and $5.50 to $7.50 for the second year.

For comparison, the Town of Cary suggests that the average costs of producing 1,000 gallons of potable water that flows from Cary to a household is best represented by their Tier 2 residential potable rate of $4.08 per 1,000 gallons. The average cost of collecting, treating and disposing 1,000 gallons that flows back to a wastewater treatment plant is represented by their sewer rate of $7.08 per 1,000 gallons. A "full circuit" for water that is used by a toilet is thus estimated to cost $11.16 per 1,000 gallons, including all annual costs to operate the utility. Thus, from the utility's standpoint, the cost of reducing household use by 1,000 gallons through the rebate program appears to be competitive with the cost of supplying that same 1,000 gallons to the household. As an additional comparison, the Town of Cary currently estimates that expansion of its capacity which is planned for 2016 will cost of the Town approximately $7 per 1,000 gallons. Again, the rebate program appears to be on a par with this cost.

A larger question is whether the rebate program is cost-effective relative to other tools the utility may undertake to manage residential indoor water demand. This question is relevant if it is the case that the utility has a mandate to undertake demand-side management programs and is choosing among programs efficiently. Other than price changes, the tool-kit for managing indoor water use is limited to subsidy/rebate programs for retrofits and educational campaigns. As indicated earlier, we are aware of no past analysis of rebate program cost-effectiveness. With regards to educational campaigns, there exists evidence that education campaigns can reduce water consumption, but the impacts may be modest and not long lasting (Ferraro and Price, 2010). Unfortunately, there has been no systematic analysis of water utility messaging that can be used to construct a cost per unit of water reduced by the campaign.

5. Conclusions

This research employs unique data combining a survey of households that participated in a high-efficiency toilet rebate program with over one-million observations on monthly water use to estimate the rebound effect associated with installation of high-efficiency toilets. Importantly, the survey also allows us to distinguish each household's motivation for replacing their toilets and thus compute the amount of water savings that is directly attributable to the rebates.

Results provide no evidence of a rebound effect with HET installation, implying the notorious issues with unsatisfactory performance of high-efficiency toilets introduced in the 1990's appear to have been largely resolved.[15] On average for our sample, replacing a pre-1991 toilet with an HET reduces household water consumption by 7.6% or 325 gallons per month, per HET installed. While many utilities (both water and electricity) have implement demand side management programs, it is rare to be guaranteed a specific reduction in water or energy use. Subsidies for low-flow shower heads, lower energy lightbulbs, energy efficiency appliances have all be associated with significant rebound effects (Greening et. al 2000; Davis 2008). High-efficiency toilets appears to be a "sure bet" among demand side management options which may make it an attractive option for utilities facing water supply constraints.

While we find little evidence of a rebound effect, our data also suggests that much of the water savings would have occurred without the rebate program. Nearly 50% of the sample indicated that they would have replaced their old toilet with HET even if the rebate program had not been available to them. As a result, the implied cost-effectiveness of the rebate program is reduced dramatically (by 123%).

The survey results raise the question of how to improve the cost-effectiveness of rebate programs. One way is to target rebates to homeowners that would not have been likely to

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[15] This is despite the recent ratings by Consumer Reports, which indicated "Our latest tests of 25 toilets show that the best performers still use the standard 1.6 gallons of water per flush." (August 2009 issue of *Consumer Reports*®, "Toilets: We found low-flow toilets that really work," available through subscription to consumerreports.org.)

replace their toilets without the rebate. To examine this potential avenue, we compared the demographic, housing and attitude data of rebate recipients who would not have replaced their toilets without the rebate and those who indicated they would have replaced their toilets without the rebate. Unfortunately, there were no significant differences among their observable characteristics.[16] Thus, it would be difficult for a utility to target its rebates and/or information on the rebate programs to increase its cost-effectiveness.

An alternative way to increase the cost-effectiveness of rebate program is to reduce the up-front cost of the rebate – i.e., to lower the rebate amount. To do so, however, may shift the incentives of the customers and result in fewer rebates being given to households that would not have replaced their toilets otherwise. Unfortunately, with the data we have available, we cannot shed light on how the incentives of households would change in response to changing rebate levels. This is an important avenue for future research, and in many ways high-efficiency toilet rebates are an ideal market to consider for these purposes. First, toilets are the largest source of indoor residential water use and therefore understanding how rebate programs affect incentives for retrofitting these appliances has significant implications for efficient water conservation policies. Second, rebates typically vary from $50 to $150 per toilet and can cover a substantial portion of the purchase price (over 100% for some models) or as little as 5% for the highest end models. Further, substitute new toilets that are not high-efficiency have similar price ranges. As such, this market is ideal for exploring the incentives of consumers to rebate amounts relative to appliance prices and relative to substitute non-efficient appliance prices.

[16] The only statistically significant difference among the groups was that households that were induced to move from a new toilet to a new HET had more individuals per household on average (2.92) as compared to households for which already planned to replace their toilets with an HET even without the rebate (2.49). See Appendix Table A1.

One caveat to the above conclusions is in order. The study is based on data from the Town of Cary, which is an affluent (median household income is $80,000) and well-educated community. The fact that the study is not representative of all U.S. households is unlikely to significantly impact the finding that there is no rebound effect. The rebound effect is largely a product of how well the toilet works. However, the affluence and high education levels of the sample may be associated with our finding that many of these toilets would have been replaced even in the absence of a subsidy. In lower income or less-educated communities one might not expect high rates of toilet replacement absent subsidies. This logic suggests that subsidization would be more cost-effective in lower income communities.

Table 1. Select demographics for HET rebate program participants.

	No. of Survey Responses	*HET Rebate Participants*	*Town of Cary*[a]
Mean Income (std. deviation)	207	\$97,705 (\$44,196)	\$83,750
Mean Age (std. deviation)	241	55.2 (13.5)	44.4
Mean No. People in Household (std. deviation)	241	2.66 (1.17)	2.94[b]
Education			
High School or Less	239	2.5%	10.6%
Some College	239	9.2%	22.1%
College	239	42.7%	36.9%
MA	239	34.7%	23.6%
Ph.D.	239	10.9%	6.8%
Race/Ethnicity			
White	232	90.1%	83.2%
Asian	232	3.4%	5.6%
African American	232	2.6%	4.1%
Hispanic or Latino	232	0.9%	3.1%
Other	232	3.0%	4.1%
Dwelling Characteristics			
Mean Age of Home (std. deviation)	238	26.12 (11.41)	18.39[b]
Mean Number of Bathrooms (std. deviation)	239	3.09 (0.81)	n/a
Mean Years Lived in Home (std. deviation)	239	14 (10.41)	10.56[b]

[a] Information on Town of Cary demographics is obtained from the Town's 2010 Biennial Citizen Survey, a phone interview of 401residents over the age of 18 in January/February 2010. The survey results are available at: http://www.townofcary.org/Departments/Administration/pio/Surveys_and_Research/2010survey.htm, last accessed October 1, 2011. Standard deviations are not available.
[b] Statistic computed from the U.S. Census Bureau Fact Sheet for the Town of Cary, 2005-2009, with data provided by the American Community Survey, available at: http://factfinder.census.gov/home/saff/main.html?_lang=en

Table 2. HET Installation Summary Statistics (N=683 households).

Installations by Households	
Total HET installations.	1,195
Mean number of HETs installed by household (std. deviation)	1.74 (0.67)
Households that received a rebate for 1 HET.	261 (38%)
Households that received a rebate for 2 HETs.	332 (49%)
Households that received a rebate for 3 HETs.	90 (13%)
HET Installations Over Time	
HET installations between June 1 and December 30, 2008	474 (40%)
HET installations between January 1 and June 30, 2009	83 (7%)
HET installations between July 1 and December, 2009	259 (22%)
HET installations between January 1 and August 31, 2010	379 (32%)

Table 3. Average monthly water consumption.

	Monthly Water Use	
	Mean	Standard Deviation
Full Sample (N=25,783)		
January 2007 to July 2010	4,538	3,163
Pre-program[a]	4,740	3,396
Pre-progam, excluding May-October 2007	4,278	2,649
Post-program[b]	4,409	3,000
Post-program, excluding May-October in each year	4,166	2,612
Rebate Recipeints Only (N=683)		
January 2007 to July 2010	4,332	2,986
Pre-program[a]	4,740	3,330
Pre-progam, excluding May-October 2007	4,229	2,462
Post-program[b]	4,052	2,699
Post-program, excluding May-October in each year	3,787	2,201
Non-rebate households (N=25,100)		
January 2007 to July 2010	4,544	3,168
Pre-program[a]	4,740	3,397
Pre-progam, excluding May-October 2007	4,279	2,654
Post-program[b]	4,418	3,007
Post-program, excluding May-October in each year	4,176	2,622

[a] Pre-program includes January 2007 through May 31, 2008.
[b] Post-program includes July 2008 through October 2010.

Table 4. Difference-in-Difference Model Results (standard errors in parentheses).

	(1)	(3)	(4)	(5)
Model:	**Basline Model**	**Basline Model**	**HET Group Fixed-Effects**	**HET Group Fixed-Effects**
Standard Errors:	**Robust**	**Clustered by HET group**	**Robust**	**Clustered by household (meter)**
Constant	4,513.15***	4,513.15***	4,512.70***	4,512.70***
	(8.53)	(40.75)	(8.18)	(15.83)
treatment_t1	-69.90**	-69.90	-139.21***	-139.21
	(33.42)	(128.35)	(31.56)	(116.47)
treatment_t2	-0.089	-0.089	-191.52***	-191.52**
	(28.96)	(106.42)	(27.68)	(96.62)
treatment_t3	316.33***	316.33	73.41	73.41
	(76.99)	(263.24)	(75.00)	(254.47)
treatperiod_t1	-354.34***	-354.34**	-313.21***	-313.21**
	(61.57)	(141.64)	(58.69)	(130.30)
treatperiod_t2	-767.45***	-767.45***	-666.58***	-666.58***
	(50.42)	(116.45)	(48.50)	(108.82)
treatperiod_t3	-913.09***	-913.09***	-983.45***	-983.45***
	(94.42)	(190.90)	(91.58)	(180.50)
Observations	4,579,439	4,579,439	4,579,439	4,579,439
R-squared	0.022	0.022	0.091	0.091

Table 5. Summary Statistics for HET Installations and Rebate Incentives.

HET Installation Summary (N=240 Households)		
Mean number of HETs installed by survey household.	2.2	
Mean satisfaction with HET performance (on a scale of 1-9, with 9 indicating "very satisfied" and 1 indicating "not at all satisfied).	8.2	
Household knew about rebate program prior to deciding to replace the toilet.	192/240	(80%)
Replacing the toilet was part of a larger renovation.	41/240	(17%)
Percentage of HETs installed by the homeowner rather than paying a plumber or installing as part of a larger renovation.[a]	50.5%	
Motivation for Replacing Toilet[b]	*# Toilets (N=485)*	
Household was not planning to replace old toilet, rebate program fully induced them to do so.	161	(33%)
Household was planning to replace old toilet with 1.6 gpf, rebate program induced them to choose HET.	98	(20%)
Household was planning to replace old toilet with an HET even without rebate.	226	(47%)

[a] If more than one HET was installed in a household, some may have been installed professionally and others by the homeowner. Respondents were asked to indicate how each toilet was installed separately.

[b] There were survey responses for 523 HET installations. However, of these, 22 respondents (across 4 HET installations) left the questions blank that would allow us to categorize how the rebate incentivized them, and another 18 households (across 34 HET installations) provided inconsistent answers and could not be categorized. Thus, the percentages of respondents in each category for "Motivation for Replacing Toilet" are computed with a base of 485 toilets.

Table 6. Cost-Effectiveness Estimates for High-Efficiency Toilet Rebate Program.

		Cost per 1,000 Gallons	
Years to replacement of original toilet in absence of the rebate program	**Yearly Annuity Payment**	**Observed Change in Water Use**	**Rebate-Induced Changes in Water Use**
Year 1: $88,000 rebates for 592 high efficiency toilet replacements			
30 years	$5,777	$2.50	$5.57
15 years	$8,555	$3.71	$8.25
10 years	$11,500	$4.98	$11.09
5 years	$20,511	$8.88	$19.78
Year 2: $60,300 rebates for 603 high efficiency toilet replacements			
30 years	$3,923	$1.67	$3.71
15 years	$5,809	$2.47	$5.50
10 years	$7,809	$3.32	$7.39
5 years	$13,928	$5.92	$13.18

Figure 1. Mean monthly water use (gallons) for 83 HET rebate participants and 25,100 matched neighbors.

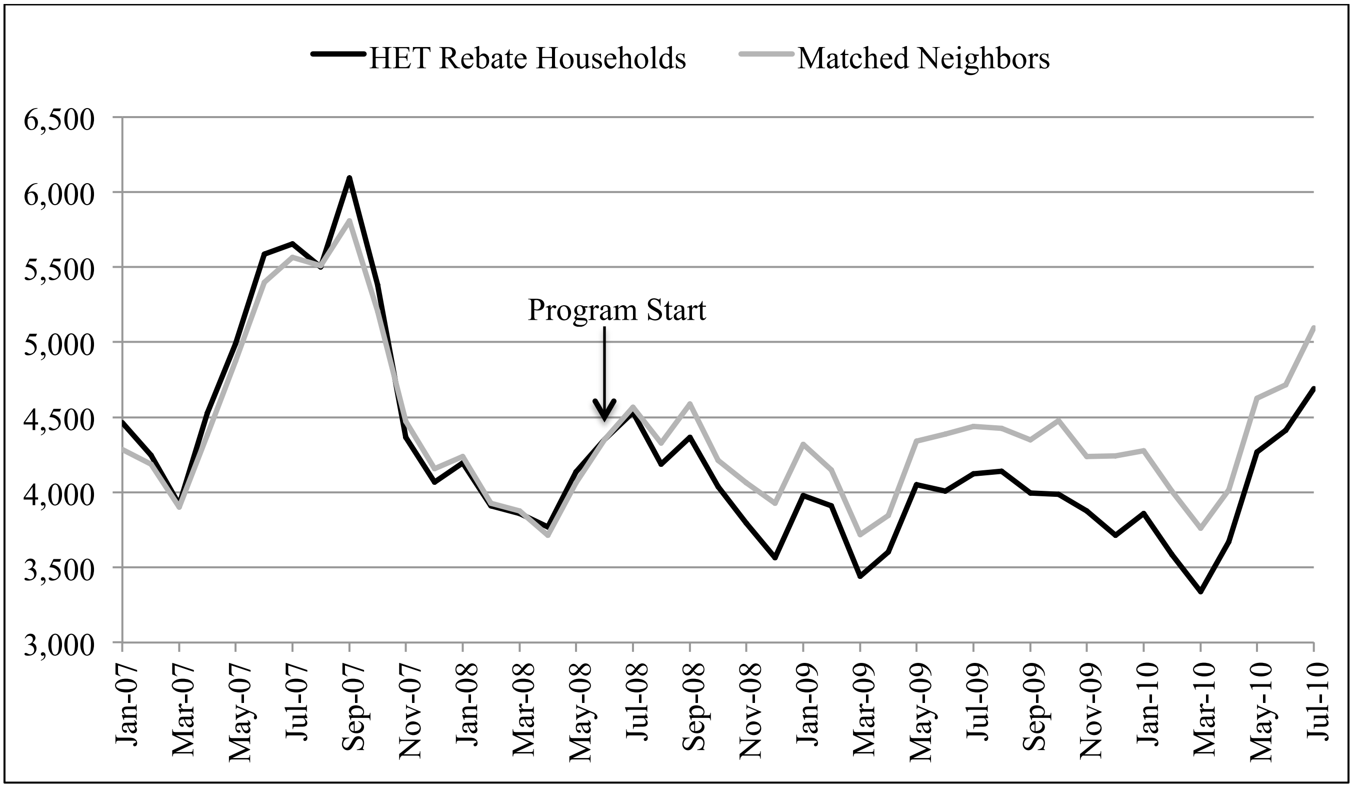

Figure 2. Survey questions determining motivation for replacement of old toilet.

Please answer the questions on this page thinking only about the toilets for which <u>you received a rebate</u>.

4. Did you know about the Town of Cary High-Efficiency Toilet Rebate Program before deciding to replace your toilets?
   a. YES
   b. NO

5. Was replacing the old toilet part of a bathroom renovation?

	Toilet 1	Toilet 2	Toilet 3
a. YES	□	□	□
b. NO, I only replaced the toilet	□	□	□

6. For toilets which you answered **YES** in question 5, would you have chosen a high-efficiency toilet even if the rebate **<u>were not</u>** available? (*If you answered only NO above, please skip to 7.*)

	Toilet 1	Toilet 2	Toilet 3
a. YES	□	□	□
b. NO	□	□	□

7. For toilets which you answered **NO** in question 5, would you have replaced the toilet with a new, but not high-efficiency toilet, if the rebate **<u>were not</u>** available?

	Toilet 1	Toilet 2	Toilet 3
a. YES	□	□	□
b. NO	□	□	□

8. For toilets which you answered **NO** in question 5, would you have replaced the toilet with a high-efficiency toilet if the rebate **<u>were not</u>** available?

	Toilet 1	Toilet 2	Toilet 3
a. YES	□	□	□
b. NO	□	□	□

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Appendix

Table A1: Differences in Household Characteristics by Size of Rebate-Induced Water Change

	No Change Induced By Rebate	Small Change Induced By Rebate	Big Change Induced By Rebate
	Mean (standard deviation)		
High Efficiency (H.E.) Dishwasher	.32 (.47)	.20 (.40)	.35 (.48)
H.E. Shower Heads	.42 (.50)	.42 (.50)	.53 (.50)
H.E. Aerator	.27 (.45)	.31 (.47)	.32 (.47)
Age of Home	29.25 (11.91)	25.46 (9.54)	29 (12.19)
Years Lived in Home	13.67 (10.36)	13.44 (9.36)	15.17 (11.02)
Age of Respondent	56 (12.68)	51.84 (13.80)	56.09 (13.85)
College Degree	.40 (.49)	.47 (.50)	.40 (.49)
Masters Degree	.34 (.47)	.31 (.47)	.44 (.50)
White	.90 (.30)	.90 (.31)	.91 (.29)
Black	.04 (.20)	.02 (.14)	.01 (.12)
Asian	.01 (.10)	.04 (.20)	.06 (.24)
Latino	.01 (.10)	.02 (.14)	0 (0)
Other	.04 (.20)	.02 (.14)	.01 (.12)
Income	96.89 (47.25)	107.07 (44.05)	95.5 (38.43)
Number in Household	2.49 (1.02)	2.92 (1.26)	2.67 (1.17)
Number of Toilets	2.24 (.85)	2.07 (.86)	2.23 (.89)
Self-Install first HET	.47 (.50)	.42 (.50)	.59 (.49)