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A Regression Discontinuity Approach to Estimating Water Demand

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Although complex pricing schedules are increasingly common in utility billing, it is difficult to determine whether consumers respond to complicated marginal prices because price changes are often confounded with simultaneous demand shocks or non-price policies. To overcome this challenge, we exploit a natural experiment - the introduction of a third price block in an increasing block pricing schedule for water - in Santa Cruz, California. Using a regression discontinuity design, we find that consumers do respond to changes in marginal price. Doubling

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JEL Classification: D12, Q21, Q25, L95

1 Introduction

In recent years, electric and water utilities have adopted increasingly complex pricing structures in order to meet their conflicting goals of promoting conservation while maintaining overall affordability. The most commonly used pricing structure is increasing block pricing (IBP). Under an IBP schedule, the price of the first few units is low, and marginal price increases with consumption. Theoretically, an IBP structure allows all consumers to purchase sufficient electricity and water to meet their basic needs, while encouraging conservation among high-use consumers.

Numerous studies have estimated the price elasticity of demand for water and electricity; most find that consumer demand is inelastic to price changes[1]. However, there are two major challenges that confound previous estimates of water and electricity demand. The first challenge is the non-experimental nature of utility pricing. Most previous studies of price elasticity rely on price variation across cities, or within one city over time. Cross-sectional studies are subject to the omitted variable bias that arises from unobserved, city-specific characteristics. For example, if Tucson is more prone to water shortages than Phoenix, it may set a higher water price, and its consumers may be more conservation-oriented. The lower demand in Tucson may be due not only to higher prices, but also to conservation measures practiced by its citizens. Longitudinal studies can avoid this problem, but often fail to control for other factors that change concurrently with prices. For example, many significant water price changes occur during droughts, when non-price policies,

[1] Dalhuisen, Florax, de Groot and Nijkamp (2003) and Espey and Espey (2004) provide meta-analyses of the literature on the price elasticity of demand for residential water and electricity, respectively.

such as rationing and conservation education efforts, are also introduced[2]. The strong correlation between weather and water or electricity use poses an additional challenge; if a price change corresponds to a particularly hot or cold year, then the price effect may be amplified, or counteracted, by the weather effect.

The second challenge associated with estimating demand is due to the complexity of the IBP schedule. Utility maximization theory indicates that a consumer faced by an IBP schedule should respond to changes in the marginal price of the block in which she consumes, as well as to changes in the marginal prices of all blocks below the one in which she consumes (Olmstead, Hanemann and Stavins, 2007). However, many authors have argued that consumers do not know, or understand, the complex schedules they face. Nieswiadomy & Molina (1989) cite a Texas study in which only 44% of water users could find, or remember, a recent water bill. Foster & Beattie (1979, 1981) argue that consumers faced with block pricing do not perform complicated utility-maximization exercises, but rather respond to average price[3]. Liebman and Zeckhauser (2004) suggest that consumers may respond only to local prices, rather than to the entire price schedule.

In this paper, we use a regression discontinuity (RD) design to estimate the effects of a change in marginal price on residential water demand under an IBP system in Santa Cruz, California. In contrast to previous studies, we are able to disentangle the effects of the marginal price change

[2] A few studies have attempted to control for the effects of non-price policies on demand. However, many of these programs - such as a prohibition on watering on consecutive days, or a discount for installing low-flow toilets - are difficult to measure quantitatively, and are often included in demand specifications as dummy variables (see, for example, Renwick & Archibald, 1998; Renwick & Archibald, 2000).

[3] Several empirical tests that distinguish between responses to marginal and average price have been developed (Opaluch, 1982; Shin, 1985; and Nieswiadomy & Molina, 1991), but the results are not conclusive. Shin (1985) studies electricity demand under a decreasing bock pricing (DBP) system and finds that consumers react to average price; Nieswiadomy and Molina (1991) analyze water demand and find that consumers faced by DBP systems react to average price, but consumers faced by IBP systems react to marginal price.

from changes in weather and other factors that affect demand. Our quasi-experimental design allows us to confirm that high-use consumers do respond to an increase in marginal price, despite the complexity of their billing structure.

Between 1990 and 1994, the Santa Cruz Water Department employed a two-block IBP system. The first eight units of water (1 unit = 100 cubic feet = 1 CCF) were priced at $0.65/unit, and additional units were priced at $1.55/unit. In 1995, a third block was introduced at 40 CCF. The marginal price for units 40 and above was $3.14, approximately double the price of the second block. Figure 1 illustrates the two-block and three-block structures. We exploit the introduction of the third block as a natural experiment, and compare the behavior of consumers who were faced with the higher marginal price, with the behavior of those who were not. Using household-level, panel data on water use, we designate households that consumed more than 40 CCF during the two summers prior to 1995, as treatment households; if they were to continue their historical water use pattern in 1995, they would face the Block 3 marginal price. Households that consumed less than 40 CCF during the two summers prior to 1995 are designated as control households; if they were to continue their historical water use pattern in 1995, they would face the Block 2 marginal price. We concentrate on July and August, the two billing months that typically have the greatest water use, and the greatest fraction of households with water use in the third price block. Using a difference-in-differences (DID) approach, we estimate the change in water use between the summers of 1994 and 1995, for treatment versus control households.

Combining the water use data with demographic data from the Census, we find that control and treatment households are systematically different; control households tend to have fewer residents, lower income, and higher housing density, as we would expect. However, once we consider only households with historical water use just above and below the 40-CCF discontinuity, treatment and control households are similar. Applying the DID approach to households near the discontinuity indicates that relative to control households, treatment households decreased water use by approximately 5 CCF (approximately 12% of average use among households near the cutoff) between 1994 and 1995. The results are robust to the inclusion or exclusion of households extremely close to the cutoff, who may not know whether they face the third price block due to the ex-post nature of water billing.

The need for the RD design, and its validity, are supported by several falsification tests. When we compare all households above and below the 40-CCF discontinuity, we find a large and significant false treatment effect prior to the introduction of the third price block. However, when we employ the RD strategy and consider only households close to the discontinuity, the false treatment effect disappears. We also find no evidence of a treatment effect at false cutoffs.

The results of the RD approach apply only to households near the 40-unit discontinuity. However, these households are an important target for water managers - they are high-use households that most likely have large outdoor watering needs, which are usually targeted during a water shortage. Our results are therefore important in the context of water management, and suggest that water managers can use high marginal prices to reduce demand among high-use consumers, while maintaining overall affordability. In a broader context, our findings imply that consumers do react to marginal prices, even when faced with complex pricing structures.

The rest of this paper is organized as follows: Section 2 describes the introduction of the third price block in Santa Cruz in 1995; Section 3 summarizes the data; Section 4 presents the empirical strategy and results; and Section 5 concludes.

2 Overview of Price Changes

California experienced a severe drought from 1987 to 1992. During this time, the Santa Cruz Water Department used price increases and various non-price controls to reduce demand. Panel (a) in Figure 2 shows bi-monthly water use from 1990 to 2000. The cyclical pattern reflects higher summer water use, due largely to outdoor watering. The periods of peak use generally correspond to the billing months of July and August. Since households are billed bi-monthly, a July water bill represents water use for the entire month of June, as well as parts of May and July; an August water bill represents water use for the entire month of July, as well as parts of June and August.

At the height of the drought in 1990, a rationing program was implemented. Under this program, a typical single family household was allocated 17 CCF every two months; units above 17 CCF were subject to a $5/unit surcharge for up to 10% over the limit, and a $25/unit surcharge above that. In 1991, heavy spring precipitation eased drought conditions and ended the need for rationing, but water use restrictions were in place, and the prices of the existing two blocks were increased. In 1992, another wet spring brought conditions closer to normal, though an excess use fee was still charged for units over 55 CCF. By 1993, the drought was over, and water use began to stabilize (Goddard, 2006). The increasing pattern of water use between 1990 and 1993, shown in Figure 2, reflects the strict water use controls in 1990, at the height of the drought, and the gradual weakening of conservation measures until 1993.

Between 1990 and 1994, Santa Cruz had a two-block IBP schedule. In 1994, the price for the first eight CCF was $0.65/CCF, and the price for additional units was $1.55/unit. Between November 1994 and January 1995, the City of Santa Cruz Water Director and Water Commission developed a plan to change the IBP structure. The prices of Blocks 1 and 2 would increase by 6% in June 1995, and by 5% in June 1996 and 1997. A third price block would be created in June 1995, and the subsequent 5% rate increases would also apply to this block. The 1996 and 1997 rates would go into effect automatically, unless the increases were no longer deemed necessary based on the Water Department's projected revenue stream. The City Council passed a resolution adopting the new rates in February 1995 (City of Santa Cruz, 1994-95). Table 2 summarizes the IBP schedule between 1990 and 2000.

Starting with the April 1995 bill, the following announcement was printed on water bills: "Attention single family residential accounts: Beware of water use over 40 CCF's per 2-month bill period. An extra $1.50 per CCF must be charged!" (City of Santa Cruz Municipal Utilities, 1996). The rate increase went into effect on the next bill. For consumers billed in April, the change was effective on the June bill; for those billed in May, the change was effective on the July bill. The 1996 and 1997 rate increases took place as scheduled in 1996 and 1997.

Most water use above 40 CCF occurs during the peak billing months of July and August; in the analysis that follows, we focus on these two months. Since households are billed bi-monthly, analyzing data from two consecutive months generally provides us with one bill for each household every year. As discussed above, summer water use is largely driven by outdoor watering needs, which are in turn driven by weather. The correlation between outdoor watering needs and water use is illustrated by Panel (b) of Figure 2, which shows average bi-monthly water use and net ETo (evapotranspiration minus rainfall, a measure of outdoor watering needs). During the drought years, there is little correlation between net ETo and water use, since use restrictions and rationing were in place. After the drought, there is a somewhat stronger correlation between temperature and water use. The cool and warm summers of 1994 and 1995 are correlated, respectively, with relatively lower and higher water use. The correlation is not perfect; temperature decreased between 1995 and 1999, but overall water use remained relatively stable.

3 Data

The primary dataset used in the analysis consists of bi-monthly water use data for all households served by the Santa Cruz Water Department, from 1990 to 2000. The data were provided by the Water Department, along with water pricing information. Households inside and outside the City were billed differently; to avoid confounding price differences with billing differences, as well as with potentially differing characteristics of households inside and outside the City, we limit our analysis to households within the City of Santa Cruz. Our household water use dataset consists of a total of 9,486 single family households, and 103,044 billing observations for July and August from 1990 to 2000.

The households were spatially matched to Census blocks and block groups using ArcGIS^{TM} software. Within each block/block group, we constructed several demographic variables (population density, housing density, income, house ownership, house age, number of rooms and bedrooms, resident age, and number of residents) that are likely to affect water use. Since our household data are from 1990-2000, we use the average value for these demographic variables from the 1990 and

2000 Census surveys. Each household within a block/block group was assigned the average value for that block/block group. Therefore, the demographic variables vary across blocks/block groups, but not over time.

The household data were also spatially matched with maximum temperature data from the PRISM Group, as well as net ETo (evapotranspiration minus rainfall, a measure of outdoor watering needs) data from the California Irrigation Management Information System (CIMIS) database. The temperature data vary across time and, to some extent, across households; the net ETo data vary across time but not across households.

Table 1 provides summary statistics for the water use, demographic, and weather data, and Table 2 summarizes the price schedules from 1990-2000[4].

4 Estimation and Results

4.1 Baseline Analysis

As discussed above, the introduction of a third price block in 1995 allows us to overcome the omitted variable bias found in most previous studies of water demand because it creates a sharp discontinuity at the start of the new block (40 CCF). Consider two types of consumers prior to 1995: high-use and low-use. Low-use consumers used less than 40 units of water, while high-use consumers used more than 40 units. Summer water use can vary greatly across years, largely due to weather fluctuations. Given the uncertainty of whether a particular summer will be warm or cold, though, it seems reasonable that a household will expect its current summer water use to be equal to its previous average summer water use. We therefore identify treatment and control households based on July/August (summer) 1993 and 1994 water use. We base our classification on 1993 and 1994 only (rather than including 1990-1992) to avoid changes in demand caused by rationing and other non-price measures implemented during the drought. Treatment households are those that consumed more than 40 CCF during the summers of 1993 and 1994; therefore, they would face the

[4]Details on data preparation and spatial matching are available from the authors upon request

Block 3 marginal price in 1995 if they continued their typical pre-1995 water use patterns. Control households are those that used less than 40 CCF during the summers of 1993 and 1994; therefore, they would not face the Block 3 marginal price in 1995 if they continued their typical pre-1995 water use patterns.

As discussed above, the price increases were first publicly discussed at a meeting in December 1994, so there is no reason to expect that people would anticipate, or sort, along the cutoff in the summer of 1994. In fact, since few citizens attended the meetings during which the price changes were discussed, it is likely that most consumers did not learn about the price increases until they were notified on their April or May 1995 water bills (Goddard, 2006).

In our initial analysis, we exclude households within 2 units of the 40-CCF cutoff. While it may be reasonable for a consumer to know her approximate water use, she will not find out her exact water use until her bill arrives, after her water use decision has been made. Households with typical, pre-1995 water use extremely close to 40 CCF may have been uncertain as to what marginal price they would face in 1995. We therefore exclude households that are within 2 units of the 40-unit cutoff (about 5% of use)[5].

Our baseline regression is:

$$Q_{it} = \beta_1 T_{it} + \beta_2 W_{it} + \alpha_{1995} + \alpha_i + \varepsilon_{it} \tag{1}$$

where
Q_{it} = quantity of water demanded by household *i* at time t
T_{it} = treatment dummy
W_{it} = weather faced by household *i* at time t
α_{1995} = dummy variable, =1 for summer 1995, =0 for summer 1994
α_i = household fixed effects

Table 3 presents the baseline estimation results. In Column (1), which includes only the treatment dummy, year dummy, and household fixed effects, the treatment effect is -4.1 CCF and is

[5] As a robustness check, we include households within 2 units of the discontinuity and obtain similar results. The results of the robustness check are presented in Section 4.3.

highly significant. Treatment households, which faced an approximately 100% increase in marginal price, reduced their water use by about 4 CCF relative to control households, which faced an increase in marginal price of a few cents. Columns (2) and (3) add maximum temperature and net ETo controls, respectively[6]. As we would expect, higher temperature and outdoor watering needs (reflected by higher net ETo) are associated with higher water use. The coefficient on the treatment dummy is slightly larger, at approximately -4.3 CCF, and remains highly significant. In Columns (4) and (5), we estimate the effects for consumers billed in July and August separately. The treatment effect is somewhat higher in July (-6.2 CCF) than in August (-3.9 CCF).

Figure 3 shows mean water use for the treatment and control groups over time. The control group's mean water use increases slightly over time, but is relatively stable. The treatment group's water use increases sharply from 1990 until 1993, then levels off. This difference in use patterns for the control and treatment households prior to 1993 deserves closer examination. According to the Water Department, typical single-family, indoor water use is 18 CCF, and water use above 18 CCF indicates outdoor water use (Goddard, 2006). The average control household in Figure 3, with water use between 10 and 20 CCF, is likely using water largely for indoor use. None of the drought restrictions - rationing at 17 CCF, use restrictions (which almost always pertain to outdoor water use), or an excess use fee at 55 CCF - would have affected the average control household to a great extent. The typical treatment household, though, with water use between 30 and 60 CCF, likely had significant outdoor water use, and was affected by the rationing and excess use fees. The loosening of drought restrictions between 1990 and 1993 is reflected in the treatment households' increase in water use over this period. Although the loosening of drought restrictions explains why treatment and control households behaved differently prior to 1995, the fact that drought restrictions affected only the treatment group also suggests that all households with water use below 40 CCF are not an appropriate counterfactual for all households with use above 40 CCF.

[6] Temperature is used in calculating ETo; therefore, it is not appropriate to include both variables in the same specification.

Mapping the locations of the treatment and control households casts additional doubt on the comparability of the two groups. As shown in Figure 4, treatment households are more likely than control households to be located away from the city center. These suburban locations suggest larger yards, leading to greater sensitivity to temperature changes, as well as other potentially unobservable differences.

4.2 Regression Discontinuity Approach

The sharp 40-unit discontinuity between the Block 2 and Block 3 marginal prices allows us to address this challenge by using an RD design. The 40-CCF cutoff was chosen for revenue reasons, and was arbitrary in terms of water use patterns. Therefore, in the RD design, we limit our analysis to treatment and control households within 15, 10, and 5 units of the 40-CCF cutoff[7].

In order for the RD approach to be valid, several assumptions must hold. The first assumption is that households do not sort non-randomly at the discontinuity. For example, the typical household in Santa Cruz consumes 18 CCF for indoor use. If the cutoff were at 18 CCF, we might be concerned that households just below the cutoff only use water for indoor purposes, and are therefore a poor counterfactual for households just above the cutoff, with outdoor water use. The 40 CCF discontinuity, though, does not correspond to any water use break-points in Santa Cruz (Goddard, 2006). Water Commission reports and information from the Santa Cruz Water Conservation Manager suggest that the 40 CCF cutoff was chosen so that the Department could meet its revenue requirements. The Water Director's reports to the Water Commission also noted that the "typical, 4-person household with modest landscape irrigation needs" required 21 CCF of water every 2 months, and that many households used double this amount (City of Santa Cruz Water Director, 1994). The 40 CCF cutoff may have been a convenient approximation of twice the typical amount of water used by a 4-person household.

[7] Like the baseline results, these estimates exclude households within 2 units of the 40-CCF cutoff. Including households within 2 units of the cutoff yields similar results, as discussed in Section 4.3.

The second assumption needed to make the the RD approach valid is that there is a single index for assigning treatment status. In our case, the index is previous summer water use. Third, factors (other than price) that affect water use should be sufficiently smooth at the cutoff. We can look for indirect evidence of this assumption by testing whether the observable variables exhibit discontinuities at the cutoff. As shown in Figure 5, the demographic variables are correlated with summer 1994 water use, but there are no visually apparent jumps at the cutoff. Table 4 provides further evidence, through t-tests, of the differences in means of demographic variables for treatment and control households. If we consider all households above and below the cutoff, control households are significantly different from treatment households across all demographic variables. However, these differences decline as we consider households within 15, 10 and 5 units of the discontinuity. None of the demographic characteristics are significantly different at the 5% level for treatment and control households within 5 units of the cutoff[8].

Figure 6 shows the locations of treatment and control households within 15, 10, and 5 units of the cutoff. The clustering of treatment households noted when all households were considered is sharply diminished; within 5 units of the cutoff, there are no visually apparent geographic differences between treatment and control households. In fact, it appears that treatment households are often located in the same block as control households, further supporting the validity of the RD design.

Table 5 presents the RD results for households within 15, 10, and 5 units of the discontinuity. The estimates range from -2.11 CCF to -5.08 CCF, and increase as we approach the cutoff; all results are significant at the 5% level. There are two possible reasons why the magnitude of the treatment effect could increase as we get closer to the cutoff. The first possibility is that households

[8] It may be misleading to simply compare the t-tests for each pair of treatment and control groups. By construction, there are fewer observations as we get closer to the discontinuity, so the t-test of a difference in means has less power. However, the magnitude of the difference in means also grows steadily smaller as we approach the discontinuity. The means vary by up to 82% for the most inclusive group, while all of the differences in the group closest to the discontinuity are less than 15%.

near the cutoff, which are different in many ways from households farther from the cutoff, may respond differently to price changes. The second possibility is that including all households in our analysis biases our results towards zero. As shown in Figure 2, the summer of 1995 was hotter than the summer of 1994. Absent the price change, we would expect all households to increase their water use between 1994 and 1995. Treatment households, with greater outdoor watering needs, would likely increase their water use by even more than the control households, and this difference between the two types of households would be greater as we move farther from the 40-CCF cutoff. Therefore, when we consider households far from the cutoff, the (positive) effect of weather on water use among treatment households, relative to control households, would attenuate the (negative) price effect. Close to the 40-CCF cutoff, the differential effects of weather on treatment and control households should be minimal.

Figure 7, which shows water use over time for households within 15, 10 and 5 units of the discontinuity, supports this hypothesis. In all of these graphs, treatment households showed stable water use between 1994 and 1995. When we consider households within 15 units of the cutoff, control households increased water use slightly. As we get within 5 units of the cutoff, the control households demonstrate a sharp increase in water use between 1994 and 1995. The difference between control households within 15 units and 5 units of the cutoff is most likely that those within 5 units of the cutoff had greater outdoor watering needs. Therefore, they were more likely to increase water use in response to the hot summer in 1995.

Figure 3, which considered all treatment and control households, showed that treatment households increased their water use rapidly when drought restrictions were lifted, while control households did not change their behavior. In contrast, Figure 7 shows that both treatment and control households near the cutoff responded similarly to the lifting of drought restrictions. The similarity of pre-treatment behavior supports the use of the control households near the cutoff as a counterfactual for treatment households near the cutoff.

The role of outdoor watering needs in driving the treatment effect is highlighted by a more detailed analysis of year-round water use. Figure 8 shows mean water use by treatment status for each billing period, including both summer and winter months. Panel (a), which considers all households, shows that treatment and control households differed in both summer and winter water use both before and after the introduction of the third price block. When we consider only households within 5 units of the cutoff in Panel (d), we find that treatment and control households had similar winter water use, but that treatment households had higher summer water use, before the introduction of the third price block. After the third price block was introduced in 1995, the treatment and control groups' summer water use patterns became similar as well.

4.3 Robustness Checks

4.3.1 Households Near the 40-Unit Cutoff

As discussed above, we excluded households within 2 units of the cutoff in the RD analysis. A consumer does not know her exact water use until she receives her bill after making her water use decision, so consumers with historical use very close to the cutoff may not know whether they will face the higher marginal price in 1995.

Nevertheless, Panel B of Table 5 shows that our results are robust to including households within 2 units of the cutoff. The estimates are somewhat attenuated compared to the results in Panel A, as we would expect. Consider a consumer who historically consumed 39 CCF. Since water use is somewhat uncertain ex-ante, we might expect her to decrease water use in order to avoid the possibility of facing the higher marginal price. This avoidance behavior among control households close to the cutoff may contribute to the slightly lower treatment effect. However, all results remain similar in magnitude to the original results, and are significant at the 10% level.

4.3.2 Falsification Tests

The demographic and geographical evidence, as well as the similarity of water use patterns from 1990 to 1994, suggest that the RD approach does identify sufficiently similar treatment and control groups. However, mean reversion remains a potential concern. For example, suppose a household typically uses less than 40 CCF, but happens to use more than 40 CCF during the summer of 1994 because of a leak or some other temporary shock. If this household is placed in the treatment group, and does not have a similar idiosyncratic shock in the summer of 1995, we would observe it consuming its normal amount of water, which would bias our treatment effect downwards. The fact that we assign a household to treatment or control status based on water use for two summers prior to 1995 helps to avoid this issue; a household will not be assigned to treatment or control status based on an idiosyncratic shock in 1994 alone. In addition, there is no reason to believe, a priori, that the treatment group does not contain as many households with *negative* shocks as with *positive* shocks, so the net effect should be zero in expectation. Nevertheless, we can conduct several falsification exercises to test whether mean reversion is driving our results. First, we look for a false treatment effect in 1994, prior to the introduction of the third price block. Second, we repeat the RD analysis at cutoffs 15 units above and below the real discontinuity (25 CCF and 55 CCF, respectively).

The test for treatment effects at false cutoffs can also address the concern that even small differences in characteristics across treatment and control households might drive the difference in water use patterns. As discussed in Section 4.1, the 40-CCF cutoff does not correspond to any natural breakpoints in water use, nor was it announced prior to our assignment of households to treatment and control status. If the small demographic differences between households just above and below the 40-CCF cutoff are driving our results, then we should expect similar results if we compare households just above and below other cutoffs.

Panel A of Table 6 presents the results of the first falsification exercise, which looks for a false treatment effect before the third price block was introduced. We assign households to treatment and control status based on water use during the summers of 1992 and 1993, and check for a false treatment effect in the summer of 1994, before the third block came into effect. Panel B of Table 6 presents the results. When we consider all households above and below the 40-CCF cutoff, there is a highly significant false treatment effect; in fact, it is larger (-4.67 CCF) than the true treatment effect (-4.08 CCF). The summer of 1994 was cooler than the summer of 1993; therefore, we would expect false treatment households to decrease their water use, relative to false control households, between 1993 and 1994, generating this effect. Once we confine our analysis to households near the cutoff, the false treatment effect disappears, and even becomes positive (though insignificant). This suggests that the treatment effect is likely to be underestimated when we consider all households; the summer of 1995 was hotter than the summer of 1994, so we would expect true treatment households to increase water use relative to true control households, between 1994 and 1995.This hypothesis is supported by the RD results, which show a larger (more negative) treatment effect for households near the cutoff.

Panel B of Table 6 presents the results from the second falsification exercise, which looks for treatment effects at false cutoffs[9]. None of the false treatment effects are significant, and four out of six have the opposite sign as the real treatment effect. The two falsification tests indicate that the RD approach is both necessary and valid.

4.4 Long-Run Results

Water demand studies generally find that long-run elasticities are higher (more negative) than short-run elasticities (Espey, Espey, & Shaw, 1997; Dalhuisen, Florax, de Groot, & Nijkamp, 2003). When faced with a higher price, a consumer can lower water use immediately in a number of ways, such as watering her lawn less frequently. Over the long run, there are even more opportunities to save water; for example, the consumer might opt to replace a washing machine with a more efficient model.

Figures 3 and 7 show the long-run behavior of treatment and control households. As we would expect, the treatment effect generally seems to increase over time. Table 7 quantifies the long-run results by presenting treatment results for 1994 through 2000[10]. When considering all treatment

[9] We only perform the analysis within 15, 10 and 5 units of the false cutoffs. If we were to include all households above and below the false cutoffs, we would pick up at least some of the true treatment effect. For example, if we were to compare all households with use above 25 CCF to all households with use below 25 CCF, some of the households with use above 25 CCF would actually be treated.

[10] Each row presents results from estimating Equation 1 for the pair of years listed, e.g., 1994 and 1996.

and control households, as well as households within 15 and 10 units of the cutoff, there is a clear upward trend in the treatment effect over time. Within 5 units of the cutoff, the increase in the treatment effect over time is not as clear. The treatment effect ranges from -3 to -5 CCF, and is not statistically significant in two of out of six cases (1994-96 and 1994-98). However, Figure 7 suggests the reason for this finding. The relatively low DID estimate for 1994-96 (-2.67 CCF) is driven not by an increase in use among treatment households, but by a sharp decrease in water use by control households. By 1995, 48% of control households had raised their water use above 40 CCF, while 42% of treatment households had lowered their water use below 40 CCF. Among all treatment and control households, only 5% of control households had raised their water use above 40 CCF, while only 14% of treatment households had lowered their water use below 40 CCF. Since many of the households close to the cutoff had switched blocks by 1995, it is not surprising that the long-run impact of the marginal price increase was not confined to the treatment group. In fact, the sharp decrease among control households from 1995 to 1996 may have been driven, at least in part, by the control households that faced the higher marginal price when they increased water use in 1995[11].

[11] It could be argued that those control households which actually faced the Block 3 price in 1995 were, in fact, treated, and should have responded to the Block 3 marginal price. We have argued that households assumed that their current summer water use will be equal to average previous summer water use. This seems reasonable, given that the most likely reason for a sharp increase in the water used by controls households in 1995 was the unusually hot summer, which was likely unanticipated. If our assumption is correct, then it is possible that some control households did not realize how high their water use was before they received their water bills, and thus reacted to the Block 2 price instead of the Block 3 price. However, if some control households correctly anticipated that they would face the Block 3 price, then our results would be attenuated (which is consistent with our finding that including households within 2 units of the cutoff, which are the most likely to cross into a different price block, lowers the treatment effect).

5 Conclusion

By exploiting the introduction of a third price block in Santa Cruz, we find that residential water demand is sensitive to an increase in marginal price. Consumers just above the 40 CCF cutoff, who were faced with a marginal price increase of nearly 100%, reduced their water use by approximately 500 cubic feet (5 CCF) compared to consumers just below the 40 CCF cutoff, who were faced with a marginal price increase of a few cents. It would be helpful to estimate the elasticity of demand for these households, in order to compare our estimates with previous studies. However, demand elasticity measures the percent change in demand for a *small* change in marginal price; given the nearly 100% increase in marginal price faced by our treatment households, discussing the elasticity of demand is not meaningful. A more appropriate measure of the size of the treatment effect is the percent reduction in water use for the average treatment household. Pre-treatment water use of treatment households within 5 units of the cutoff was approximately 43 CCF, so a decrease of 5.1 CCF corresponds to a 12% reduction in demand. The long-run evidence suggests that the increase in marginal price had a lasting impact on water use.

The quasi-experimental nature of our analysis makes an important contribution to the literature. Unlike most previous studies, which are faced with omitted variable bias across cities or time, we disentangle the effects of a marginal price increase from potential confounding factors. From a policy perspective, this study provides support for the use of price increases as a water demand management tool. In a broader context, it suggests that even when consumers face complex billing structures, they do respond to changes in marginal price. In this case, the marginal price increase was nearly 100%, so we cannot rule out the possibility that a large price change may be required in order to affect behavior. Since an IBP system allows utility managers to target large price increases at high-use consumers, our findings also indicate that IBP structures can be effective in constraining demand among high-use consumers while maintaining overall affordability.

References

City of Santa Cruz, Various Meeting Minutes (1994-95).

City of Santa Cruz Municipal Utilities, SCMU Report (April 1996).

City of Santa Cruz Water Director, 1995 Water Rate Study (November 1994).

Dalhuisen, Jasper M., Raymond J. G. M. Florax, Henri L. F. de Groot, and Peter Nijkamp, "Price and Income Elasticities of Residential Water Demand: A Meta-Analysis," *Land Economics* 79: 2 (2003), 292–308.

Deller, Steven C., David L. Chicoine, and Ganapathi Ramamurthy, "Instrumental Variables Approach to Rural Water Services Demand," *Southern Economic Journal* 53 (1986), 3346.

Espey, M., J. Espey and W. D. Shaw, "Price Elasticity of Residential Demand for Water: A Meta-Analysis," *Water Resources Research* 33:6 (1997), 1369-1374.

Espey, James A. and Molly Espey, "Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities," *Journal of Agricultural and Applied Economics* 36:1 (2004), 65–81.

Foster, Henry S. and Bruce R. Beattie, "Urban Residential Demand for Water in the United States," *Land Economics* 55:1 (February 1979), 43–58.

Foster, Henry S. and Bruce R. Beattie, "Urban Residential Demand for Water in the United States: Reply," *Land Economics* 57: 2 (May 1981), 257–265.

Goddard, Toby, Phone Conversations (March 13, April 3, and June 16, 2006).

Liebman, Jeffrey B. and Richard J. Zeckhauser, "Schmeduling," Working Paper, Kennedy School of Government, Harvard University (2004).

Nieswiadomy, Michael L. and David J. Molina, "Comparing Residential Water Demand Estimates under Decreasing and Increasing Block Rates Using Household Data," *Land Economics* 65: 3 (1989), 280–289.

Nieswiadomy, Michael L. and David J. Molina, "A Note on Price Perception in Water Demand Models," *Land Economics* 67: 3 (1991), 352–359.

Olmstead, Sheila, Michael W. Hanemann, and Rob Stavins, "Water Demand Under Alternative

Price Structures," *Journal of Environmental Economics and Management* 54 (2007), 181–198.

Opaluch, James J., "Urban Residential Demand for Water in the United States: Further Discussion," *Land Economics* 58: 2 (1982), 225–227.

Renwick, Mary E. and Richard D. Green, "Do Residential Demand-Side Policies Measure Up? An Analysis of Eight California Water Agencies," *Journal of Environmental Economics and Management* 40 (2000), 37–55.

Renwick, Mary E. and Sandra O. Archibald, "Demand-Side Management Policies for Residential Water Use: Who Bears the Conservation Burden?," *Land Economic*s 74: 3 (1998), 343–359.

Shin, Jeong-Shik, "Perception of Price when Price Information is Costly - Evidence from Residential Electricity Demand," *Review of Economics and Statistics* 67:4 (1985), 591–598.

TABLE 1: SUMMARY STATISTICS

	No. Obs.	Mean	Std. Dev.	Min	Max
Bi-Monthly Water Bill					
Consumption (CCF)	103,044	22.44	16.39	1	887
Demographic Variables					
Population Density (people/1000 m^2)	9,486	2.61	1.46	0.00	14.69
Housing Density (houses/1000 m^2)	9,486	1.08	0.62	0.00	7.12
Bi-Monthly Income ($)	9,486	8,399	2,283	2,865	16,464
Fraction Owned	9,486	0.59	0.19	0.01	0.89
House Age (Years)	9,486	36.20	10.69	18	56
No. Rooms	9,486	5.00	0.84	2.1	7.05
No. Bedrooms	9,486	2.49	0.53	0.5	3
Age of All HH Residents	9,486	35.65	5.40	9.5	53.35
No. Residents	9,486	2.5	0.8	0.8	23.0
Weather Variables					
Maximum Temperature (degrees C)	142	23.11	2.11	18.87	28.63
Net Eto (inches)	22	4.79	0.67	2.87	5.74

Summary statistics for household water use, demographic characteristics, and weather in July and August 1990-2000. 1 CCF = 100 cubic feet. The number of observations for all demographic variables corresponds to the number of households in the panel dataset, since the demographic data vary across households, but not time. Net ETo (evapotranspiration minus rainfall) varies across time, but not households, yielding one observation for each July and August billing period from 1990-2000. Maximum temperature data vary geographically (to some extent), as well as across time. Since households are billed for the previous 2 months' use, net ETo and temperature data from the month prior to the billing month are used. *Source: Author's calculations, based on household water use data from the City of Santa Cruz; demographic data from the 1990 and 2000 Census surveys; ETo and rainfall data from CIMIS; and maximum temperature data from the PRISM Group.*

TABLE 2: WATER PRICING SCHEDULE

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997-2000**
Block 1 Rate, 1-8 CCF ($/CCF)	0.46	0.60	0.60	0.65	0.65	0.69	0.72	0.76
Block 2 Rate, 9-39 CCF ($/CCF)	0.84	1.35	1.35	1.55	1.55	1.64	1.73	1.81
Block 3 Rate, 40+ CCF ($/CCF)	–	–	–	–	–	3.14	3.23	3.31
Fixed Cost ($/Bi-Monthly Bill)	9.36	14.40	14.40	15.60	15.60	16.80	17.40	18.00

Nominal water prices for the City of Santa Cruz. 1 CCF = 100 cubic feet. *Source: City of Santa Cruz Water Department.*

TABLE 3: BASELINE RESULTS

	Baseline	Weather Controls	Weather Controls	July Only	August Only
	(1)	(2)	(3)	(4)	(5)
"Treated" Dummy	-4.086***	-4.334***	-4.340***	-6.212***	-3.907***
	(0.857)	(0.855)	(0.855)	(1.766)	(0.971)
Year 1995 Dummy	2.535***	1.870***	2.662***	1.827***	2.992***
	(0.092)	(0.133)	(0.096)	(0.139)	(0.122)
Max. Temperature (degrees C)		0.223***			
		(0.035)			
Net ETo (inches)			0.319***		
			(0.05)		
Obs.	16679	16679	16679	6134	10545
R^2 (within)	0.063	0.066	0.066	0.055	0.072
R^2 (between)	0.535	0.453	0.534	0.390	0.560

Dependent variable is bi-monthly water use in hundreds of cubic feet (CCF). "Treated" is a dummy variable that takes on a value of one if a household consumed more than 40 CCF in July/August of 1993 and 1994, zero if a household consumed less than 40 CCF in July/August of 1993 and 1994. Households within 2 units of the 40-CCF cutoff are excluded. All specifications include year and household fixed effects, and show the difference-in-differences (DID) result between treatment and control households for water use from July/August 1994 to July/August 1995. Max. Temperature = maximum temperature for the calendar month prior to the billing period. Net ETo = evapotranspiration minus rainfall, measured in inches, for the calendar month prior to the billing period. Temperature is used in calculating ETo; therefore, it is not appropriate to include both variables in the same specification. Standard errors are in parentheses, and are clustered at the household level. *, **, and *** represent significance at the 10%, 5% and 1% levels, respectively.

TABLE 4: DEMOGRAPHIC VARIABLES BY TREATMENT STATUS

	All HHs				+/- 15 Units			
	Control	Treatment	Δ	t-test	Control	Treatment	Δ	t-test
Population Density (people/1000 m^2)	2.73	1.56	1.17	19.64	2.44	1.85	0.59	5.87
Housing Density (houses/1000 m^2)	1.13	0.63	0.50	19.76	0.99	0.76	0.23	5.52
Bi-Monthly Income ($)	8,172	10,340	-2,168	23.56	8,871	9,555	-684	3.96
Fraction Owned	0.58	0.71	-0.13	16.64	0.63	0.67	-0.04	3.08
House Age (Years)	36.66	32.47	4.19	9.29	35.66	34.13	1.53	1.88
No. Rooms	4.93	5.62	-0.69	20.07	5.18	5.38	-0.20	3.29
No. Bedrooms	2.45	2.81	-0.36	16.25	2.60	2.73	-0.13	3.47
Age of All HH Residents	35.26	39.07	-3.81	17.09	36.45	38.02	-1.57	3.82
No. Residents	2.49	2.58	-0.09	2.59	2.57	2.51	0.06	0.93
No. Control Households	7,745				1,206			
No. Treatment Households	595				199			
	+/- 10 Units				+/- 5 Units			
	Control	Treatment	Δ	t-test	Control	Treatment	Δ	t-test
Population Density (people/1000 m^2)	2.39	1.93	0.46	3.39	2.22	1.95	0.27	1.32
Housing Density (houses/1000 m^2)	0.96	0.80	0.16	2.89	0.90	0.80	0.10	1.09
Bi-Monthly Income ($)	8,973	9,433	-460	1.89	9,450	9,406	44	0.11
Fraction Owned	0.63	0.67	-0.04	2.05	0.66	0.68	-0.02	0.60
House Age (Years)	35.46	34.36	1.10	1.00	35.73	34.90	0.83	0.47
No. Rooms	5.22	5.34	-0.12	1.41	5.34	5.34	0.00	0.03
No. Bedrooms	2.60	2.68	-0.08	1.43	2.66	2.66	0.00	0.05
Age of All HH Residents	36.68	38.05	-1.37	2.38	37.92	38.40	-0.48	0.49
No. Residents	2.62	2.45	0.17	1.23	2.52	2.45	0.07	1.32
No. Control Households	479				106			
No. Treatment Households	112				48			

Differences in demographic variables households above and below the 4000 cubic foot (40 CCF) water use discontinuity. Treatment households are those with historical water use above 40 CCF; control households are those with historical water use below 40 CCF. Households within 2 units of the 40-CCF cutoff are excluded. *Source: Author's calculations, based on household water use data from the City of Santa Cruz, and demographic data from the 1990 and 2000 Census surveys.*

TABLE 5: REGRESSION DISCONTINUITY RESULTS

Panel A: Excluding Households Within 2 Units of the Cutoff				
	All HH	+/- 15 Units	+/- 10 Units	+/- 5 Units
"Treated" Dummy	-4.09***	-2.12**	-3.18***	-5.08**
	(0.86)	(0.93)	(1.18)	(2.10)

Panel B: Including Households Within 2 Units of the Cutoff				
	All HH	+/- 15 Units	+/- 10 Units	+/- 5 Units
"Treated" Dummy	-3.56***	-2.21***	-2.53**	-4.15*
	(0.76)	(0.84)	(1.10)	(2.17)

Dependent variable is bi-monthly water use in hundreds of cubic feet (CCF). "Treated" is a dummy variable that takes on a value of one if a household consumed more than 40 CCF in July/August of 1993 and 1994, zero if a household consumed less than 40 CCF in July/August of 1993 and 1994. All specifications include year and household fixed effects, and each row shows the difference-in-differences (DID) result between treatment and control households for water use from July/August 1994 to July/August 1995. Column headings indicate how close to the 40 CCF water use discontinuity each regression was conducted. Panel A presents results from the baseline analysis, which excludes households within 2 units of the 40 CCF water use discontinuity. Panel B presents results that include households within 2 units of the 40 CCF water use discontinuity. Standard errors are in parentheses, and are clustered at the household level. *, **, and *** represent significance at the 10%, 5% and 1% levels, respectively.

TABLE 6: FALSE TREATMENT RESULTS

Panel A: False Treatment Prior to Introduction of Third Block				
	All HH	+/- 15 Units	+/- 10 Units	+/- 5 Units
1993-94 False Treatment	-4.67***	-0.60	0.06	1.93
	(1.05)	(1.20)	(1.37)	(2.49)

Panel B: False Cutoffs				
	All HH	+/- 15 Units	+/- 10 Units	+/- 5 Units
25 CCF False Cutoff	–	0.14	0.15	-0.45
		(0.32)	(0.38)	(0.64)
55 CCF False Cutoff	–	-0.31	0.19	0.19
		(1.83)	(2.37)	(3.76)

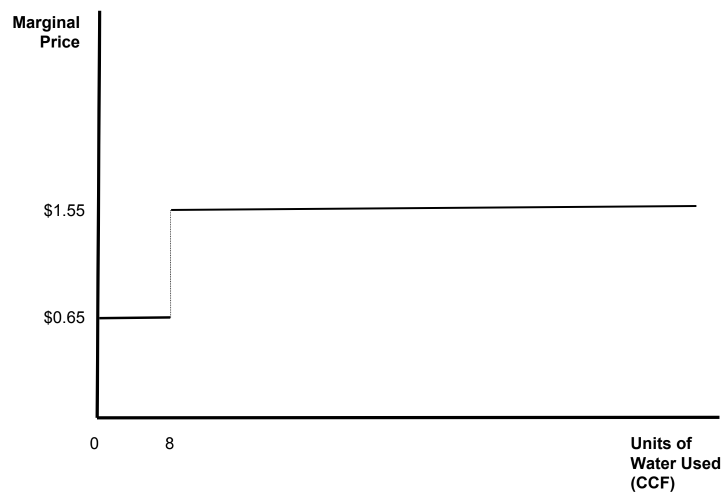
Dependent variable is bi-monthly water use in hundreds of cubic feet (CCF). In Rows (1) and (2), households are assigned to "false" treatment and control status based on historical water use above and below false 25 and 55 CCF cutoffs, respectively. "Treated" measures the DID between false treatment and control households from July/August 1994 to July/August 1995. In Row (3), households are assigned to "false" treatment and control status based on summer water use above and below 40 CCF in July/August 1992/1993. "Treated" measures the DID between false treatment and control households from July/August 1993 to July/August 1994, before the third price block was introduced. All specifications include year and household fixed effects. Column headings indicate how close to the cutoffs each regression was conducted. Standard errors are in parentheses, and are clustered at the household level. *, **, and *** represent significance at the 10%, 5% and 1% levels, respectively.

TABLE 7: LONG-RUN RESULTS

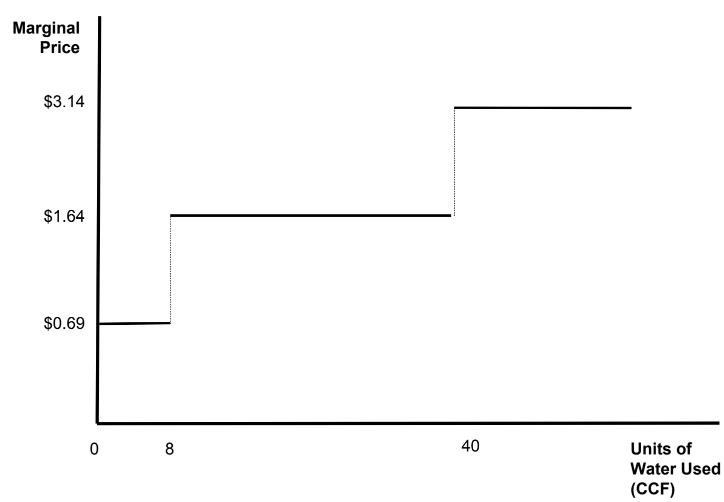
	All HH	+/- 15 Units	+/- 10 Units	+/- 5 Units
1994-95	-4.09***	-2.12**	-3.18***	-5.08**
	(0.86)	(0.93)	(1.18)	(2.10)
1994-96	-7.80***	-2.93***	-3.06**	-2.67
	(0.91)	(1.12)	(1.43)	(2.37)
1994-97	-8.93***	-4.99***	-3.90**	-5.16**
	(0.98)	(1.2)	(1.77)	(2.3)
1994-98	-11.13***	-4.44***	-4.58***	-4.07
	(0.99)	(1.29)	(1.7)	(2.72)
1994-99	-10.96***	-7.12***	-7.91***	-5.93**
	(1.04)	(1.28)	(1.71)	(2.95)
1994-2000	-9.58***	-6.91***	-6.64***	-5.90**
	(1.11)	(1.57)	(1.73)	(2.86)

Dependent variable is bi-monthly water use in hundreds of cubic feet (CCF). "Treated" is a dummy variable that takes on a value of one if a household consumed more than 40 CCF in July/August of 1993 and 1994, zero if a household consumed less than 40 CCF in July/August of 1993 and 1994. Households within 2 units of the 40-CCF cutoff are excluded. All specifications include year and household fixed effects. Each row shows the difference-in-differences (DID) result between treatment and control households for summer water use between the listed years. Column headings indicate how close to the 40-CCF cutoff each regression was conducted. Standard errors are in parentheses, and are clustered at the household level. *, **, and *** represent significance at the 10%, 5% and 1% levels, respectively.

FIGURE 1: BLOCK PRICING SCHEDULE



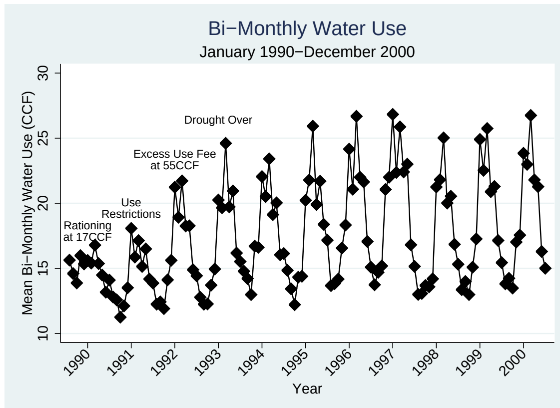
(a) 1994: Two-Block Structure



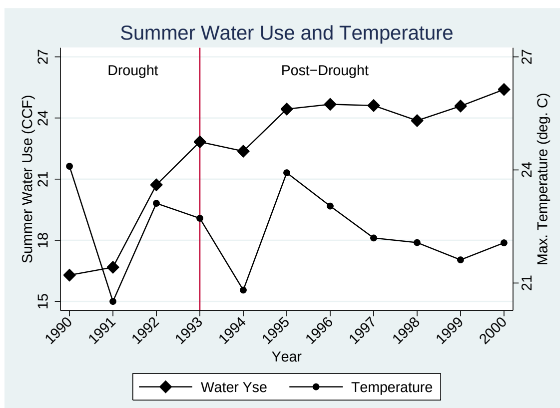
(b) 1995: Three-Block Structure

Increasing block pricing (IBP) schedule for residential water in Santa Cruz in 1994 and 1995. In 1994, there were two price blocks, with a break point at 800 cubic feet (8 CCF). In 1995, the Water Department introduced a third price block at 40 CCF. *Source: Based on price data from the City of Santa Cruz Water Department.*

FIGURE 2: BI-MONTHLY WATER USE



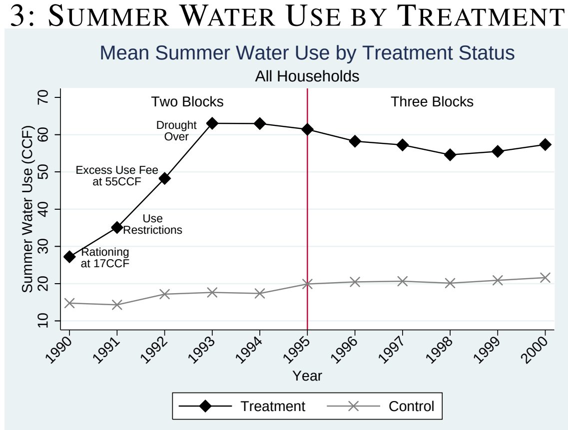
(a) Bi-Monthly Water Use



(b) Summer Water Use

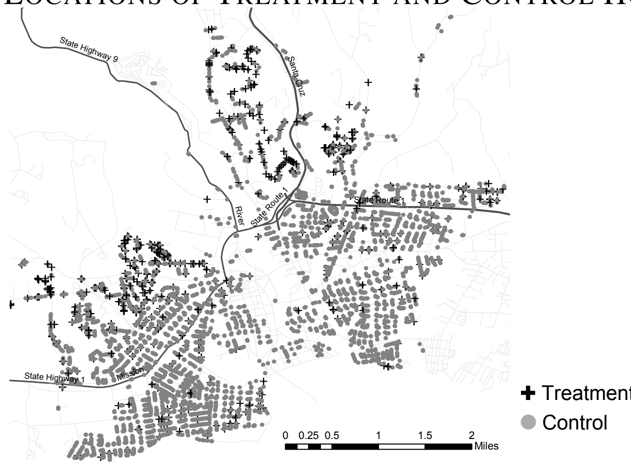
Panel (a) shows average bi-monthly water use in hundreds of cubic feet (CCF) for all households. Panel (b) shows average summer water use, as well as maximum temperature in degrees Celsius, for all households. *Source: Author's calculations, based on household water use data from the City of Santa Cruz.*

FIGURE 3: SUMMER WATER USE BY TREATMENT STATUS



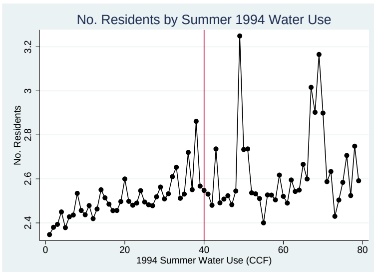
Mean summer water use in hundreds of cubic feet (CCF) in July/August for all treatment and control households over time. Treatment households are those with historical water use above 40 CCF; control households are those with historical water use below 40 CCF. Households within 2 units of the 40-CCF cutoff are excluded. The vertical line divides pre-treatment years (1989-1995) from post-treatment years (1995-2001). *Source: Author's calculations, based on household water use data from the City of Santa Cruz.*

FIGURE 4: LOCATIONS OF TREATMENT AND CONTROL HOUSEHOLDS

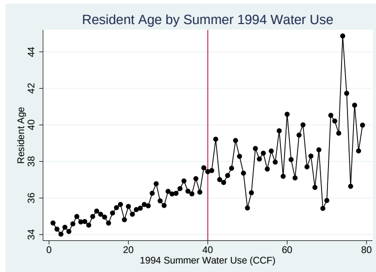


Locations of treatment and control households. Treatment households are those with historical water use above 4000 cubic feet (40 CCF); control households are those with historical water use below 40 CCF. Households within 2 units of the 40-CCF cutoff are excluded. *Source: Author's calculations, based on water use data, provided by the City of Santa Cruz and geocoded using ArcGIS™ software.*

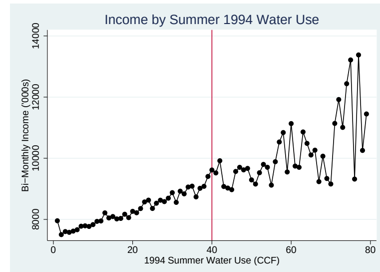
FIGURE 5: DEMOGRAPHIC VARIABLES BY SUMMER 1994 WATER USE



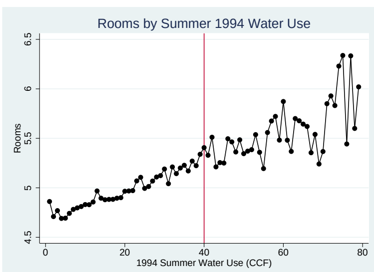
(a) No. Residents



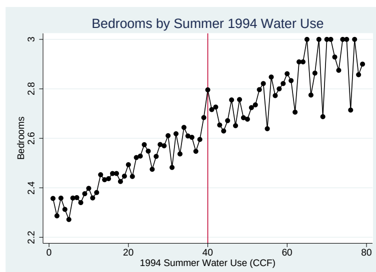
(b) Resident Age



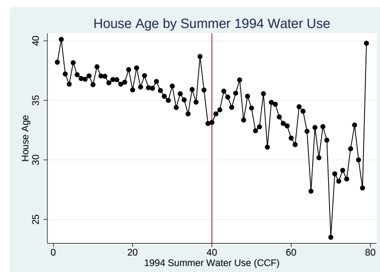
(c) Income



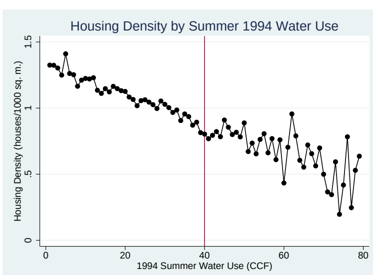
(d) No. Rooms



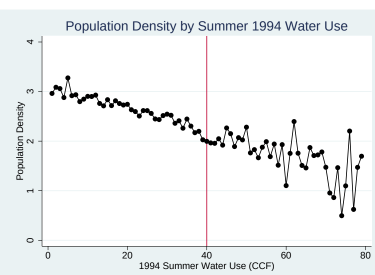
(e) No. Bedrooms



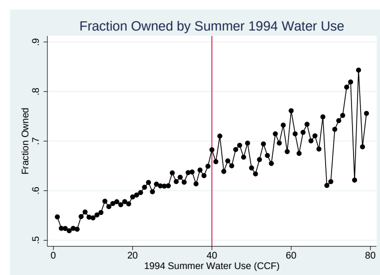
(f) House Age



(g) Housing Density



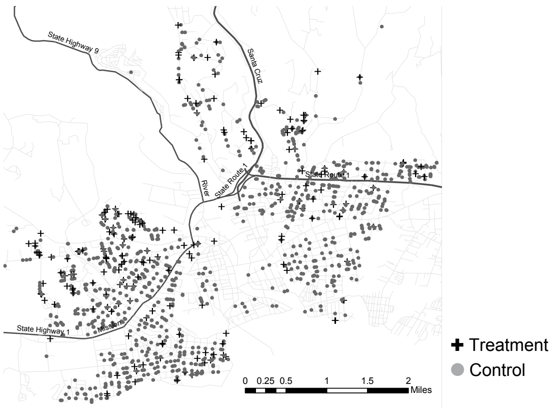
(h) Population Density



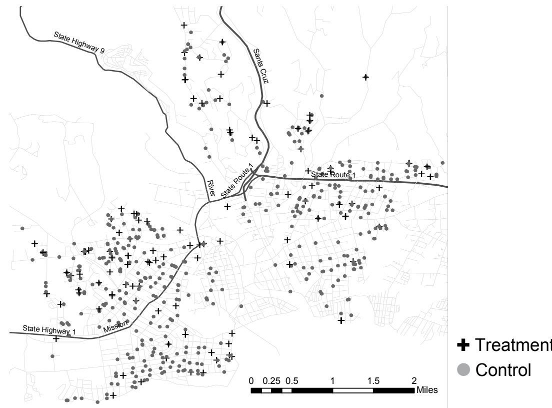
(i) House Ownership

Average household demographic characteristics by 1994 water use. The vertical line marks the 4000 cubic foot (40 CCF) water use discontinuity. Treatment households are those with historical water use above 40 CCF; control households are those with historical water use below 40 CCF. *Source: Author's calculations, based on household water use data from the City of Santa Cruz and demographic data from the 1990 and 2000 Census surveys.*

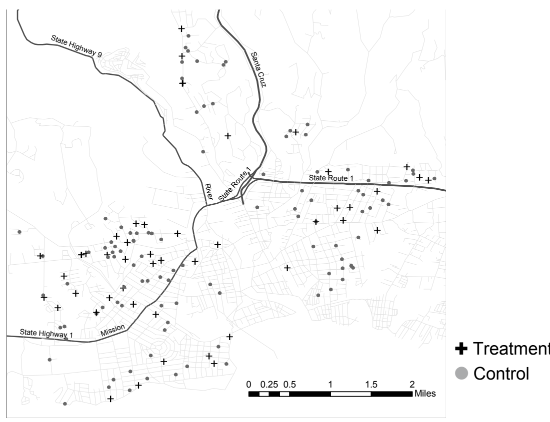
FIGURE 6: LOCATIONS OF TREATMENT AND CONTROL HOUSEHOLDS NEAR THE CUTOFF



(a) Households within 15 Units



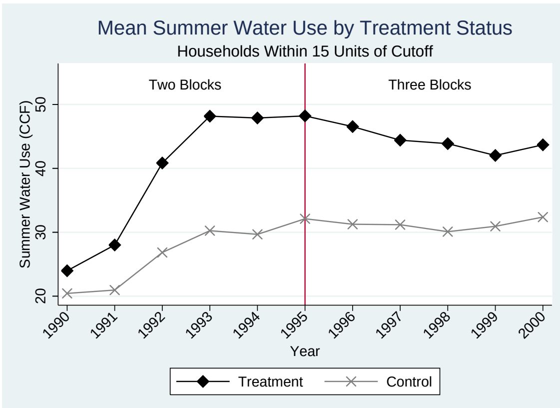
(b) Households within 10 Units



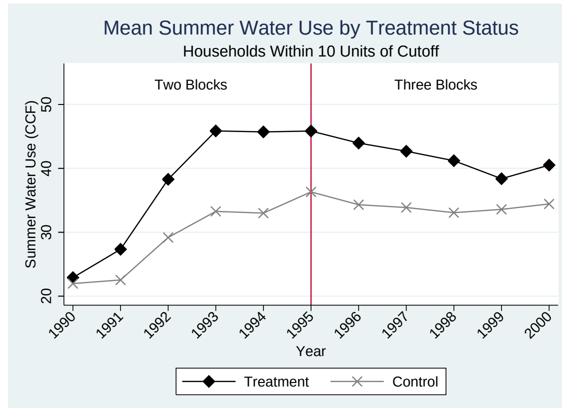
(c) Households within 5 Units

Locations of treatment and control households within 15, 10, and 5 units of the 4000 cubic foot (40 CCF) discontinuity. Treatment households are those with historical water use above 40 CCF; control households are those with historical water use below 40 CCF. Households within 2 units of the 40-CCF cutoff are excluded. *Source: Author's calculations, based on water use data, provided by the City of Santa Cruz and geocoded using ArcGIS^{TM} software.*

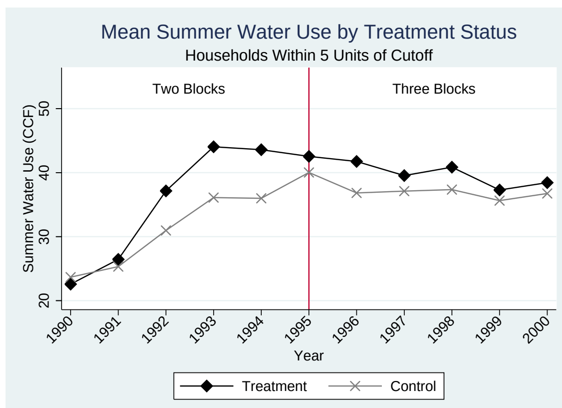
FIGURE 7: SUMMER WATER USE BY TREATMENT STATUS NEAR THE CUTOFF



(a) Households within 15 Units



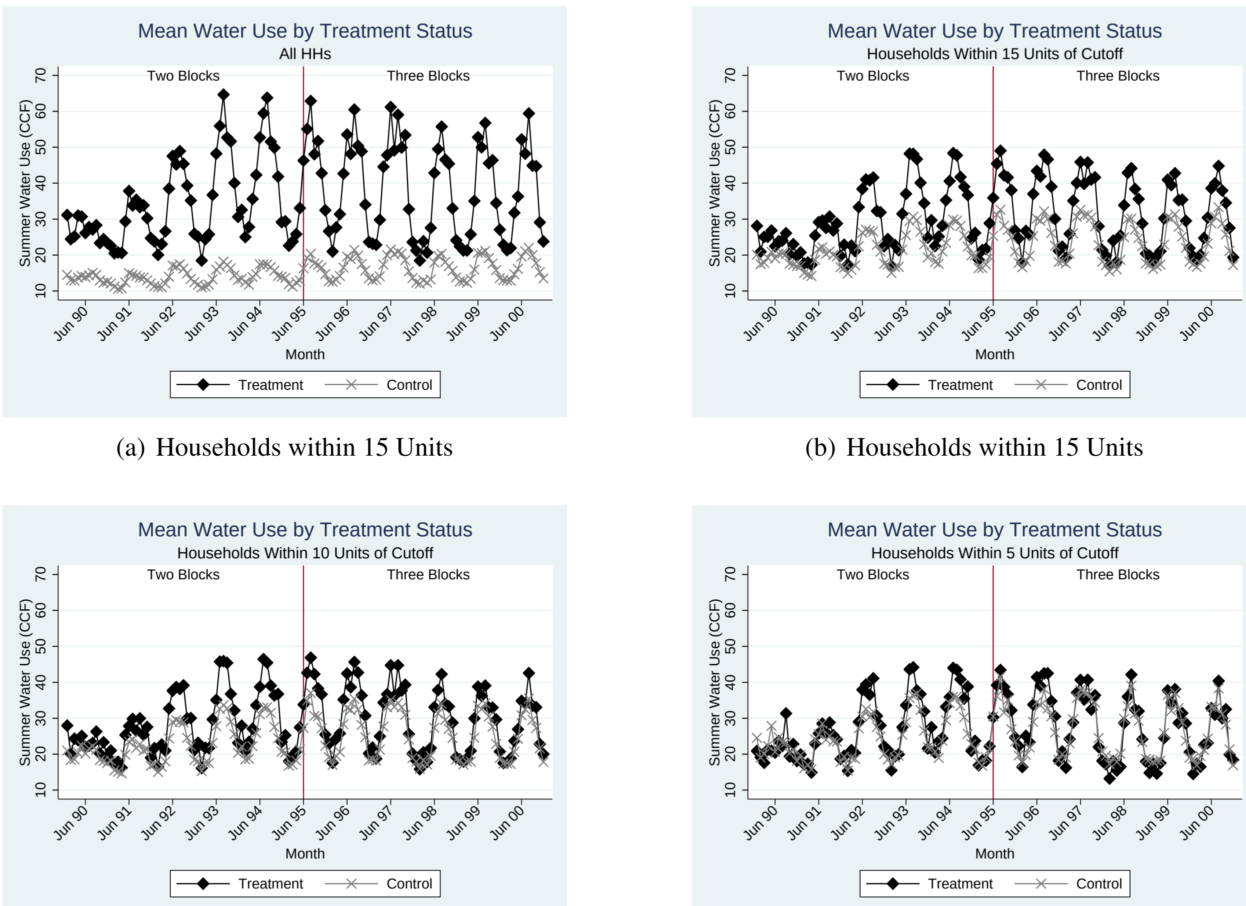
(b) Households within 10 Units



(c) Households within 5 Units

Mean summer water use in hundreds of cubic feet (CCF) in July/August for treatment and control households. Treatment households are those with historical water use above 40 CCF; control households are those with historical water use below 40 CCF. Households within 2 units of the 40-CCF cutoff are excluded. The vertical line illustrates the introduction of the third price block, beginning at 40 CCF, in 1995. Panels (a), (b) and (c) show households within 15, 10 and 5 units of the 40 CCF discontinuity, respectively. *Source: Author's calculations, based on household water use data from the City of Santa Cruz.*

FIGURE 8: YEAR-ROUND WATER USE BY TREATMENT STATUS



(a) Households within 15 Units

(b) Households within 15 Units

(c) Households within 10 Units

(d) Households within 5 Units

Mean bi-monthly water use in hundreds of cubic feet (CCF) for treatment and control households. Treatment households are those with historical water use above 40 CCF; control households are those with historical water use below 40 CCF. Households within 2 units of the 40-CCF cutoff are excluded. The vertical line illustrates the introduction of the third price block, beginning at 40 CCF, in 1995. Panels (a), (b) (c), and (d) show all households, and households within 15, 10 and 5 units of the 40 CCF discontinuity, respectively. *Source: Author's calculations, based on household water use data from the City of Santa Cruz.*