ABSTRACT

Title of Dissertation:	ESSAYS ON THE EFFICIENT MANAGEMENT OF WATER RESOURCES
	Andrew B. Rosenberg, Doctor of Philosophy, 2019
Dissertation directed by:	Professor Lars J. Olson, Department of Agricultural and Resource Economics; Associate Professor David A. Newburn, Department of Agricultural and Resource Economics

In the first analysis of this dissertation, I assess the water use savings and cost-effectiveness of the Conservation Reserve Enhancement Program (CREP) in the Upper Arkansas River basin in Kansas, a water rights retirement program aimed at reducing depletion of the High Plains Aquifer. First, I use a fixed effects model with matched samples of farmers to determine the effect of CREP on water use. I find that for every unit of authorized water use retired in CREP, 0.8 units of water are saved per year. Second, I examine how a rights retirement program would perform outside of the policy region and how the existing program design could be improved upon. I estimate a probit regression to determine which factors most influence the probability that a farmer enrolls in CREP. Using the results of the probit regression, I then simulate enrollment decisions outside of the policy region to assess the cost-effectiveness of different incentive designs. I find that programs that pay incentives based on past levels of water extraction save

water more cheaply than programs that pay based on acreage retired. I also find that programs such as CREP that offer higher incentive rates to farmers that enroll later are more efficient than programs that never increase rates.

In the second analysis, coauthors and I assess the household value for stream restoration, a common approach used by local governments to mitigate the water quality impacts of urban stormwater. We conduct a choice experiment in the Baltimore metro region to examine household willingness to pay (WTP) for stream restoration. We vary the land ownership of restoration locations and the distance from households to streams in hypothetical choice scenarios that include changes in several stream restoration attributes. Our results indicate that household WTP for improvements in stream bank stabilization and nutrient reduction are positive and significant on public and private land across all distances. We find significant heterogeneity in WTP across land ownership and proximity to a stream. This heterogeneity in WTP can be of particular interest to policy makers when making decisions about where, and even how, to restore streams.

ESSAYS ON THE EFFICIENT MANAGEMENT OF WATER RESOURCES

by

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2019

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Foreword

The ninth and tenth chapters of the following dissertation are jointly authored with David A. Newburn and Charles A. Towe. The Dissertation Committee acknowledges that Andrew B. Rosenberg made substantial contributions to this work.

Acknowledgements

I have received an immense amount of support in completing this dissertation. First and foremost, I would like to thank my wife Susan, who has been by my side in this process from the beginning. Her continual positivity has helped me to stay on track during the most difficult parts of this process. I would also like to thank my parents. They have provided me with insight and advice when I've needed it and are always there to listen.

Next, I would like to thank my co-chairs. David Newburn for the countless hours he has devoted to working with me, helping me to learn to be a better researcher and writer. Also for funding me for three years and asking me to participate in several research projects. I have benefited immensely from these experiences. Lars Olson for reading countless drafts of my work and always providing comments that help me to see for myself what questions I should be asking. Also for encouraging me to make strong economic arguments and to own my research. I would also like to thank Erik Lichtenberg, Jorge Holzer and Anna Alberini for always providing challenging feedback. I would like to thank Maureen Cropper for graciously devoting time to serve in my committee despite her many other commitments. Finally, I would like to thank Stephen Salant for encouraging me to pursue my interests and helping me to develop new economic ideas around them.

I would like to thank Daniel Voica for always having words of wisdom. Thank you also to my friends and colleagues. This includes Cyrus, Youpei, Uttara, Mark, Tristan, Davide and many others. I would also like to thank the AREC staff who have always helped me with my constant barrage of questions. This includes Jeff Cunningham, Katherine Faulkner, Pin-Wuan Lin, Dany Burns and Ally Delgado.

Several external people or organizations were also particularly helpful. I would like to thank several individuals from the state of Kansas for providing data, helpful insights and other assistance whenever I requested it. I couldn't have completed this dissertation otherwise. This includes Steve Frost, Alex Whitesell and Ginger Pugh from the Department of Agriculture and Brownie Wilson from the Kansas Geological Survey. I would also like to thank the many individuals who provided helpful input for the stream restoration survey. Finally, I would like to thank Peter Groffman and the Cary Institute for their help in funding me in my fifth year.

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Chapter 1: Introduction

Water managers are faced with the formidable task of ensuring that water is in adequate supply and condition for a variety of competing purposes. Some purposes of water, such as hydroelectric power, simply demand its plentiful flow. However, many others such as recreation, drinking water, or ecological uses also require that water is of a certain quality. In a simple world, economic efficiency would be the main consideration for managing water scarcity and quality. However, in practice other considerations hold sway and water resources are managed inefficiently over both space and time.

A few factors make it difficult to manage water efficiently. First, in places like the United States, existing institutions and land use patterns are suboptimal for managing water scarcity and quality. Property rights systems fail to efficiently allocate water amongst potential uses over space and time, and existing land use patterns and agricultural practices fail to provide an adequate level of water quality. Second, profit or utility-maximizing individuals have little incentive to help provide the socially efficient levels of water use and quality. Water users rarely pay a price that reflects the true social value of water and thus they do not use water efficiently over space or time. Further, land owners or developers whose land use decisions adversely impact water quality have little incentive to change their practices. These individuals resist taxes or regulations and in effect these policies are relatively rare.

Despite these difficulties, water managers still must find ways to conserve limited water supplies and improve water quality. To overcome the institutional and political constraints outlined above, managers often favor voluntary incentive-based policies. Incentive-based policies can help to achieve water management goals, but can also have perverse consequences. For example, policies have been implemented which help farmers pay the cost of adopting efficient irrigation technology. Although in some cases more efficient irrigation systems can reduce water consumption, in other cases they can increase consumption (Pfeiffer and Lin 2014). Managers must carefully consider the direct and indirect impacts of incentive-based policies to ensure that they can achieve management goals effectively. When possible, managers may prefer to avoid private decision makers altogether. However, this may be too limiting. For example, if water managers only manage stormwater that runs through public land, they will likely fail to achieve water quality goals, as most water flows through private property.

In this dissertation, I assess some of the impacts of current policies aimed at achieving water management goals, with an eye towards informing the design of more efficient future policy. I assess two current policies for managing water use and quality, respectively. In chapters two through eight, I analyze the water use savings and cost-effectiveness of the Conservation Reserve Enhancement Program (CREP) in the Upper Arkansas River basin in Kansas, a water rights retirement program aimed at reducing depletion of the High Plains Aquifer. Water rights retirement programs provide incentives for farmers willing to voluntarily stop irrigating their land. I find that CREP offers a viable way to manage a depleting aquifer and I consider ways that management using similar mechanisms can be made more cost-effective in the future. In chapters nine and ten, coauthors and I analyze the household willingness to pay for stream restoration, a common approach used by local governments to improve water quality. This analysis aims to identify how the benefits of restoration vary across the landscape. The results may help to inform future policy decisions about where the benefits from stream restoration are highest.

My first analysis focuses on a promising groundwater management approach that could help to make water use more efficient in many areas of the world. Groundwater accounts for 94% of all freshwater resources and many of the world's most highly productive aquifers are rapidly depleting. Climate change as well as rising food demands from increasing population and incomes will increase the need for groundwater to irrigate cropland. Meanwhile, most areas allocate groundwater inefficiently, using a queuing system such as prior appropriation (Schoengold and Zilberman 2007). In prior appropriation, each water right is allocated a maximum annual quantity of water that must be applied to a particular plot of land and come from a specific water source. Further, groundwater is a common property resource, meaning that without appropriate water prices individual farmers have little incentive to save groundwater for future use. Under prior appropriation, rights holders who currently only pay the cost of pumping water are unlikely to welcome higher water prices, thus groundwater continues to be overused in most areas.

Water rights retirement programs like the Conservation Reserve Enhancement Program of Kansas are one way to restore some level of market efficiency over space and time for an allocative rights system. CREP pays farmers to retire their water rights, effectively buying out the least productive uses of water. Thus the policy conserves groundwater for more productive future use. The CREP policy region in Western Kansas is a highly important agricultural region, thus warrants this analysis on its own. The High Plains Aquifer has experienced considerable depletion in the policy region due to intensive irrigation and low groundwater recharge. Groundwater levels in the policy region have dropped as much as 150 feet since 1950. In addition, the results of the study can also help to inform future policies. The Upper Arkansas River CREP was one of the first water rights retirement programs and the highly detailed farmer-level data offered by the state of Kansas have proved immensely helpful in the analysis. The results of chapters two through eight provide insights that will be relevant to both current and future water rights retirement programs in groundwater management areas that use allocative water rights systems.

I analyze water rights retirement programs in two ways. First, I assess the current program's effectiveness at reducing water for those that enroll. I find that for every unit of authorized use that is retired, about 0.8 units of water use is saved per year, making CREP one of the most highly effective voluntary incentive policies. In this part of the analysis, I account for the possibility that farmers that enroll are individuals with expectations of low future water use, which could undermine the program's objective. I do not find evidence that this sort of adverse selection occurs. Second, I evaluate the cost-effectiveness of the current program compared to other potential policy designs and suggest some ways that could affect the efficiency of similar incentive-based policies. I find that the most cost effective policies, which base incentives on past use and which increase rates over time are 14% more cost-effective than the current incentive design used with CREP, which uses incentives based on acreage retired and also increases rates over time.

In the second analysis, coauthors and I examine issues with efficient management of water quality. We examine how the value of stream restoration varies based on whether a stream is restored on private or public land. Stream restoration is one of the most widely used interventions to address urban stormwater runoff and improve water quality. Many jurisdictions such as Baltimore County and City have chosen to use stream restoration as a major way to meet water quality goals. Further, the majority of existing stream restoration projects have been built on public land, largely due to ease of access. However, since the majority of streams run through private property, if jurisdictions would like to restore streams on a larger scale, they will need to restore streams on private land. Policy makers will then want to assess whether the benefits of stream restoration on private land are adequate.

We conducted a choice experiment in the Baltimore metro region to examine household willingness to pay (WTP) for stream restoration. We use its results to ask two main questions. First, which types of stream restoration attributes bring the highest value? Second, does the household WTP for restoration attributes vary by land ownership and proximity to a stream? In our choice experiment, we vary the land ownership of restoration locations and the distance from households to streams in hypothetical choice scenarios that include changes in several stream restoration attributes. Our results indicate that household WTP for improvements in stream appearance and pollution reduction are positive and significant on public and private land across all distances. We find significant heterogeneity in WTP across land ownership and proximity to a stream. Further, we find that in general, there is less support for restoration on private streams in other people’s neighborhoods, but the difference is only sometimes significant. Because the type and location of stream restoration projects are selected by policy makers this heterogeneity in the WTP can be of particular interest when making decisions about where to restore streams.

Both analyses aim to provide information that is useful for the efficient management of water resources. The first analysis highlights a current policy with considerable water use savings for those that enroll, then provides evidence for policies that could achieve similar savings in a more cost effectiveness way. One wonders whether CREP is only effective because it focuses on a small subset of farmers for which savings can be achieved relatively cheaply. However, the policy seems to be a step in the right direction for groundwater managers that have struggled to find viable ways to reduce water use from irrigators. The second analysis examines an important source of spatial heterogeneity in benefits from stream restoration. Its results could be useful for a water manager who wants to either offset the costs of meeting a certain nutrient or sediment reduction target, or who wants to maximize the benefits from a certain amount of water quality management activity.

Chapter 2: Do Water Rights Retirement Programs Effectively Reduce Irrigation?

In much of the world, farmers pay little or no price for water access and lack the option to sell their water to those who could use it more efficiently. Farmers that use groundwater also have limited incentive to conserve over time, as their well levels largely depend on surrounding farmers' water use. This has accelerated the depletion of many of the world's most productive groundwater sources, including the High Plains and Central Valley aquifers in the United States (Gleeson et al. 2012). Most economists would prefer to address water scarcity with prices or other market-based policies, but political opposition and physical constraints often make these difficult to implement. Policy makers have favored measures such as restrictions on new appropriations or cost-sharing incentives for efficient irrigation systems. Recently, some states have also offered incentive payments for farmers willing to retire their irrigation rights (Sophocleous 2012). Considerable attention has been given to water prices, water markets, and cost-share incentives.[1] However, only a few existing studies have considered water rights retirement programs as a viable solution to reduce irrigation.

In this study, I evaluate the impact of an existing water rights retirement program on water use and then examine ways that future water rights retirement schemes can be made more cost-effective in achieving water savings. I empirically

[1] Guilfoos, Khanna, and Peterson (2016) offer a good overview of the water pricing and marketing literature as it pertains to groundwater. Pfeiffer and Lin (2014a) discuss the literature on cost sharing for efficient irrigation systems.

analyze a panel dataset of farmer water use and enrollments in the Conservation Reserve Enhancement Program (CREP) in the Upper Arkansas River Basin (UAR), a water rights retirement program implemented in Western Kansas. First, I determine the impact of CREP enrollment on farmer water use using fixed effects regressions. Because CREP is a voluntary program, farmers that retire their water rights may differ than those that do not. To account for this sample selection, enrolled farmers are matched with similar unenrolled farmers from both inside and outside of the policy region prior to estimating panel models of water use. A matched sample is created using covariate matching with calipers and is then used to estimate fixed effects models of water use. One model specification tests whether farmers increase water use in the immediate years before enrollment in order to qualify for the program. Second, I evaluate the cost-effectiveness of different water rights retirement program designs using simulations of farmer enrollment. Panel binary choice regressions estimate the impact of CREP incentive payments and farmer characteristics on program enrollment. These estimates are then used to simulate farmer enrollment decisions outside of the policy region (Lewis and Plantinga 2007; Mason and Plantinga 2013). Simulated enrollment decisions are combined with water use data for farmers outside the CREP policy region to determine which types of incentives are the most cost-effective in achieving water savings.

The literature on agricultural water use has highlighted the difficulty of finding policies that effectively save water. Some studies have focused on incentive payments for efficient irrigation systems (Ding and Peterson 2012; Pfeiffer and Lin 2014a), which can actually increase farmer water use (Pfeiffer and Lin 2014a). Others focus on more traditional economic tools like taxes, quantity restrictions or water rights markets (Thompson et al. 2009; Guilfoos, Khanna, and Peterson 2016), but these approaches usually have limited political support or high implementation costs (Tsur and Dinar 1997; Guilfoos, Khanna, and Peterson 2016). In recent years, several theoretical studies have hypothesized about the potential effects of rights retirement programs (Wheeler et al. 2008; Ding and Peterson 2012; Wang, Park, and Jin 2015), but fewer studies have assessed their impacts empirically. One exception is Monger et al. (2018), who estimate the effect of the level of incentive rates on enrollment in CREP. However, the following is the first economic study to empirically examine the effect of rights retirement programs on water use. This analysis also contributes to the literature examining the environmental effects that can be directly attributed to voluntary incentive programs (Mezzatesta, Newburn, and Woodward 2013). A voluntary program requiring the retirement of irrigation rights could attract a subset of farmers who value their water rights less than others. Thus, it is important to examine the extent to which incentive payments actually reduce water use. Finally, several studies simulate land use decisions to evaluate the cost-effectiveness of incentive-based policies (e.g., Lewis and Plantinga 2007; Lewis et al. 2011). However, this is the first study to simulate farmer enrollment to assess the cost-effectiveness of water rights retirement programs. Policy makers looking for more efficient ways to reduce farmer water use could gain insight from these findings.

The analysis yields several main findings and policy implications. First, fixed effects models using matched samples of farmers reveal that, for each unit of authorized water use that is retired in CREP, about 0.8 units of water is saved per year. This means that CREP does not attract low water use farmers and actually attracts farmers with above average annual water use. The high water savings attributable to CREP contrast with the low savings associated with previous policies aimed at reducing irrigation. These large water use reductions are partially attributable to the program's eligibility requirements, which only allow intensely irrigated land to be enrolled. However, water savings attributable to CREP far exceed those that would be expected based on eligibility requirements alone. This suggests that there is not a strong relationship between the value of water rights and levels of water use. Second, the analysis does not find evidence that farmers increase water use after program announcement in an attempt to qualify for the program. Instead, farmers actually ramp down their water use as they prepare to retire their rights. Then a regression of CREP enrollment decisions finds that factors that increase the probability of enrollment include: higher incentive payments; lower soil productivity; higher erodibility of soil; and lower amounts of remaining water in the underlying aquifer. Results from the enrollment regression are applied in simulations of alternative retirement programs to assess their cost-effectiveness for water use reduction. Policy simulations suggest that incentive rates based on levels of prior water use are more cost-effective in achieving water savings than rates based on retired acreage. Lastly, retirement policies can be made more cost-effective by increasing incentive rates over time. Rollouts of incentive rates are more cost-effective because they are able to capture unobserved differences in the willingness to accept of farmers to retire their water rights. The most cost-effective policies of those simulated in this study are those that both base incentive rates on prior water use and that increase offered rates over time.

Chapters 3 through 8 analyze the effectiveness of CREP at reducing water use. Chapter 3 provides a more in-depth analysis of the relevant literature. This is followed by chapter 4, which provides policy background about water rights in Kansas and the Upper Arkansas River CREP program. After that, the data used in the analysis are clarified in chapter 5 and then the econometric strategies used in the analysis are outlined in chapter 6. The fixed effects model is first described, then the approach for evaluating cost-effectiveness of programs is outlined. Finally, in chapter 7 the results of the regression analysis and simulation are discussed and conclusions are drawn in chapter 8.

Chapter 3: Water Management, Additionality and Cost-Effectiveness

Many different approaches for managing groundwater have been examined in the literature. Water prices have received considerable attention. Shah, Zilberman and Chakravorty (1993) explore the use of prices for groundwater pumping. They show that the optimal level of groundwater pumping occurs when the marginal benefit of extraction equals the marginal pumping cost plus the opportunity cost of lost future water supplies. However, because groundwater is a common property resource, users are unlikely to account for the opportunity cost when making their use decisions. Thus a water price should be set at the opportunity cost of water supplies. However, such a price would be both difficult and costly to implement due to high costs of monitoring and enforcement. As an alternative, the authors suggest using a price based on irrigation system used and crop choice as a second best policy solution (Shah, Zilberman and Chakravorty 1993). In addition to being difficult to monitor, groundwater prices are likely to be met with political resistance, particularly when the benefits of conservation are concentrated in small areas (Guilfoos, Khanna, and Peterson 2016).

Water markets are sometimes used as an alternative to prices, although usually to manage surface water. Some relatively successful surface water markets have been set up in Australia and South Africa. Nieuwoudt, Armitage and Backeberg (2001) find that for water markets in South Africa, high water scarcity, relatively low transaction costs, and a heterogeneous group of users leads to more trades. However, markets can be difficult to implement with existing water rights systems such as prior appropriation. South Africa transferred rights from private to public ownership and Australia decoupled rights from land before marketing water (Schoengold and Zilberman 2007). Considerably less attention has been given to markets for groundwater (Thompson et al. 2009). Thompson et al. (2009) find that a cap and trade system for managing groundwater leads to a more efficient allocation of water use over space, but does not necessarily reduce overall water use. Guilfoos, Khanna, and Peterson (2016) find that locally managed groundwater markets that consider future consequences of extraction are needed to allocate water use most efficiently over the life of an aquifer.

Voluntary incentive programs are another way to encourage water conservation. Several studies have examined the impacts of cost-share programs for efficient irrigation systems, such as the Environmental Quality Incentives Program (Ding and Peterson 2012; Pfeiffer and Lin 2014a). Pfeiffer and Lin (2014a) find that in some cases, increases in irrigation efficiency may actually lead to increases in water use due to increased profitability of applied irrigation water. However, they also find that when farmers adopt irrigation systems that improve irrigation efficiency more substantially, there is a significant drop in use. Pfeiffer (2009) looks at the effect of acres enrolled in the Conservation Reserve Program (CRP) on water use at the county level. She finds that the effect is small, probably because the CRP does not explicitly target water use reduction and farmers that enroll are unlikely to enroll irrigated cropland.

A small literature looks at the effects of water rights retirement programs in particular. Several theoretical analyses have examined rights retirement or temporary buyout programs (e.g., Wheeler et al. 2008; Ding and Peterson 2012; Wang, Park, and Jin 2015). Wheeler et al. (2008) find that longer term buyouts have a larger effect on water savings than short term buyouts, but are less cost-effective. Ding and Peterson (2012) use an optimization model to examine the cost-effectiveness of water rights retirement programs in Kansas. They find that lower crop prices and groundwater levels, both of which lower the value of water, are highly influential for decisions about whether or not to enroll in such programs. Even fewer empirical studies have examined water rights retirement programs. Monger et al. (2018) use a binary choice model to determine which factors influence enrollment in CREP in the Republican River Basin of Colorado. They find that the level of incentive payments, the water levels of a well, closeness to streams and soil quality all significantly impact enrollment. However, they do not investigate the extent to which CREP impacts consumptive water use, or evaluate the program's cost-effectiveness. As of yet, no one has empirically examined the water use effects and cost-effectiveness of water rights retirement programs.

This analysis also contributes more broadly to the literature analyzing the environmental impacts and cost-effectiveness of incentive-based conservation policies. The extent to which desired environmental outcomes are directly attributable to a conservation program is sometimes called additionality in the literature. Different designs for voluntary incentive programs can lead to different amounts of additionality (Lichtenberg 2014). Additionality of a program is particularly relevant when the incentivized conservation approach can benefit farmers even without incentives. In such situations, incentives for adoption of a certain practice may pay farmers for doing something they would do anyway. Further, if a conservation program only attracts a subset of farmers, that subset may be among those for whom the conservation program changes their behavior the least. Various incentive-based conservation policies exist and their levels of additionality vary considerably. For example, using propensity score matching, Mezzatesta, Newburn, and Woodward (2013) find that cost-share incentives for different agricultural BMPs have vastly different levels of additionality. Lichtenberg (2014) explains why disparities in additionality may occur, comparing the design of different conservation programs. Programs with more stringent eligibility requirements, like EQIP, tend to result in more additionality than conservation programs with looser requirements such as the CRP (Lichtenberg et al. 2011). Further, the potential for slippage, or increases in productive activity in areas that are not conserved as a result of incentive payments, as has occurred with the CRP, can further reduce additionality (Roberts and Lubowski 2007; Lubowski, Plantinga and Stavens 2008). The results of this study suggest that, among those studied, CREP is one of the most highly additional incentive-based conservation policies. One reason for this may be its strict eligibility requirements, the details of which are discussed in the next chapter. However, the high additionality attributable to CREP far exceeds those expected from its eligibility requirements alone. This result implies that more valuable water rights are not necessarily used for more intensive irrigation.

Another important strain of literature focuses on mechanisms for improving the cost-effectiveness of conservation programs. Ideally, managers could rank individuals based on their willingness to accept for adopting a conservation practice divided by the additional environmental benefits attributable to their enrollment. Policy mechanisms may be designed to approach this ideal policy in the face of asymmetric information between farmers and managers, which results from farmers knowing the value of their water rights and their future activities better than managers. Two of the main mechanisms analyzed in the literature to address asymmetric information include optimal contracts and auctions (Latacz-Lohmann and Schilizzi 2005). For example, Mason and Plantinga (2013) find that optimal contracts could increase forest cover at only 40% of the costs of using uniform incentive rates. For conservation, auctions are more commonly used in practice and have been studied in detail. Auctions can be much more cost effective than fixed prices. Discriminant auctions, which pay winning bidders their exact bid amounts, can achieve higher water savings for a given budget if bid shading is minimal. Alternatively, uniform priced auctions can be beneficial if the distribution of underlying compliance costs is unknown and the manager would like to reveal this distribution to set an appropriate cost (Latacz-Lohmann and Schilizzi 2005).

However, auction mechanisms often do not perform as intended. The CRP uses an auction mechanism to make payments to farmers that conserve land and has historically made payments to all farmers with bids below an unrevealed bid cap. Landowners tend to learn the level at which bids are capped over time, eroding any cost savings from the auction mechanism (Reichelderfer and Boggess 1998). However, some other more targeted auction programs such as BushTender in Australia found large gains in cost-effectiveness (Latacz-Lohmann and Schilizzi 2005). The following analysis assesses some relatively unstudied mechanisms for improving the cost-effectiveness of incentive-based programs. I find that these mechanisms lead to substantial improvements in cost-effectiveness over fixed incentive policies. They provide an alternative to auctions for improving the cost-effectiveness of conservation programs, particularly when auctions create significant barriers to program participation. In particular, I find that policies based on past water use improve cost-effectiveness considerably, tying program costs more to the policy objective of water savings. I also find that policies that increase rates over time improve cost-effectiveness because they get farmers with the lowest value for water to enroll earliest by starting with a low incentive. They can then gradually get farmers with higher value water rights to enroll by gradually offering higher rates.

Chapter 4: Water in Kansas and the Conservation Reserve Enhancement Program

The High Plains is a region of the United States known for intensely irrigated agriculture. The underlying High Plains Aquifer system (See Figure 4.1) is the semiarid region's primary source of water. An aquifer is an underground permeable rock formation that allows for storage of water, where its depth is generally determined by the presence of impermeable bedrock. For the region of Kansas overlying the High Plains Aquifer, groundwater accounts for approximately 99% of total reported water use, 95% of which is used for irrigated agriculture (Schloss, Buddemeier, and Wilson 2000). Due to intensive use over many years, the saturated thickness of the aquifer, or the height of water from its bedrock, has depleted substantially. As a result, in many areas across the region, policy makers have been searching for ways to reduce aquifer depletion while retaining the health of the local agricultural-based economy.

The primary means for allocating water in Kansas, as in most of the Western United States, is through the prior appropriation doctrine. In times of shortage priority is assigned to those rights that were claimed the earliest and all water rights must be used for an approved beneficial use. In Kansas, following the Water Appropriations Act of 1945, each water right is assigned a maximum annual quantity and rate of water use associated with particular places of use and points of diversion (Peck et al. 1998). Due to initial declines in levels of the High Plains Aquifer in Western Kansas, efforts to restrict new water appropriations started in the late 1970s. However, by that time too much water had already been allocated. In many locations, the rate of water being pumped from the aquifer each year is significantly higher than the rate of recharge. Declines have been highest in the portion of the aquifer in Western Kansas, which has low annual rainfall and where aquifer recharge is negligible (Sophocleous 2012). Figure 4.1 shows the estimated usable lifetime of the High Plains Aquifer underlying Kansas, calculated by the Kansas Geological Survey. In many areas in Western Kansas that rely on intensive irrigated agriculture, the aquifer is expected to have less than 25 years of water left.

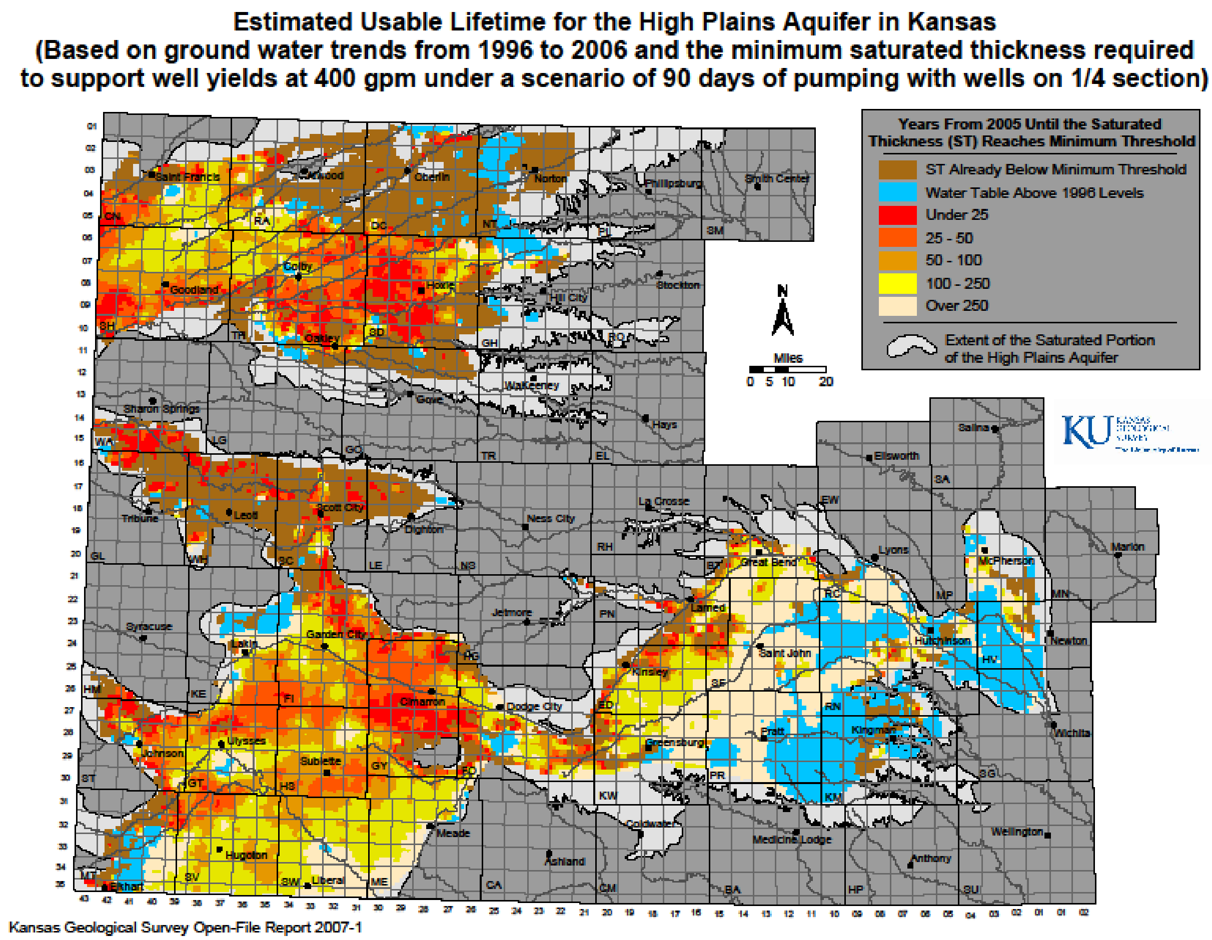

Figure 4.1: Estimated usable lifetime of High Plain Aquifer in Kansas
Source: Kansas Geological Survey

The reality of water rights in Kansas limits the policy choices available for slowing aquifer depletion. Most water governance of the aquifer is controlled by the five Groundwater Management Districts (GMD), which represent the management needs of five distinct aquifer regions. GMDs have mainly implemented policies limiting new appropriations. This includes well spacing regulations and safe yield policies that reject new appropriations in areas that are already over-appropriated. However, policies that restrict new appropriations have no effect on the water use of existing appropriators. Restrictions on use are hard to implement because water rights holders are protected from uncompensated takings by the government, so that rights are held in perpetuity as long as they are used. Alternatives to quantity restrictions, such as water banks and cost-share incentives for more efficient irrigation systems have been unsuccessful at reducing water use. Recently, Kansas has been one of several agricultural states to experiment with water rights retirement programs. This includes the Water Rights Transition Assistance Program (WTAP) and the Upper Arkansas River Conservation Reserve Enhancement Program (CREP), the latter of which this study examines in detail. WTAP pays incentives for irrigators to retire their water rights in critically depleted areas and is an interesting opportunity for future research (Sophocleous 2012).

Administered by the Farm Service Agency (FSA) of the United States Department of Agriculture (USDA), CREP is a part of the Conservation Reserve Program (CRP), which funds private land conservation. Nationwide, CREP addresses state and national environmental issues related to agricultural land use and offers compensation to farmers who replace land in agricultural production with native vegetation. Voluntary participants receive annual rental payments from the FSA, in addition to other incentives often paid by the participating state (United States Department of Agriculture [USDA] 2007). The Kansas legislature initially approved funding for the Upper Arkansas River (UAR) CREP program in 2007. The Kansas Water Office (KWO), FSA and Natural Resources Conservation Service (NRCS) of the USDA worked together to implement the program in late 2007 (Kansas Department of Agriculture 2017). The UAR CREP offers annual rental payments and cost-sharing for conservation practices from the USDA, as well as a one-time signing bonus from the KWO. In exchange, enrolled farmers must adopt an approved conservation practice, cease irrigation and permanently retire their water rights. An eligible conservation practice must be put in place for the duration of the contract, which is 14 to 15 years long. After that the farmer may return to dryland agriculture. The program's stated goals are to protect water quality and to slow depletion of the aquifer in the policy region.

The UAR CREP is offered in parts of ten counties in Southwestern and South Central Kansas (see figure 4.2). Initially, the program was capped at 20,000 acres, but in 2011 was expanded to allow up to 28,950 enrolled acres. The cap has not yet been reached. There are county limits on acreage enrolled as well, which were recently reached in Gray and Kearny counties. However, the Kansas legislature allowed expansion of the county caps in 2017 and enrollments from these counties have continued. The program is targeted towards high water use irrigators on highly erodible soils. Eligibility for the program is based on historical water use for the water right and plot of land to be retired. To be eligible, at least a half acre-foot (AF) of irrigation water per acre must have been used in four of six specified years and at least 50% of the maximum annual quantity authorized with the retired right must have been used in any three of the past five years (USDA 2007). Annual enrollment payments from the FSA were initially set at $100-125 per acre of irrigated land retired, were increased to $115-140 per acre in 2011 and again to $153-193 in 2015 (USDA 2007). These payments vary based on HUC 8-digit watershed and type of irrigation system. One-time payments from the state of Kansas were initially set at $62 per acre or $35 per acre depending on a designation of soil tier 1 or 2 respectively. Tiers are based on soil erodibility. In 2016, these rates were increased to $97 and $55 per acre for tier 1 and 2, respectively. As of 2018, a total of 22,479 acres of irrigated farmland from 145 water rights have been retired (USDA, 2007). As can be seen in table 4.1, spikes in enrollment in the program are highly associated with rate increases. Both FSA rate hikes occurred late in the year. Consequently, many farmers did not enroll until the year after, especially after the rate hike in 2011. This study exploits these rate increases to analyze the impacts of incentives on enrollment.

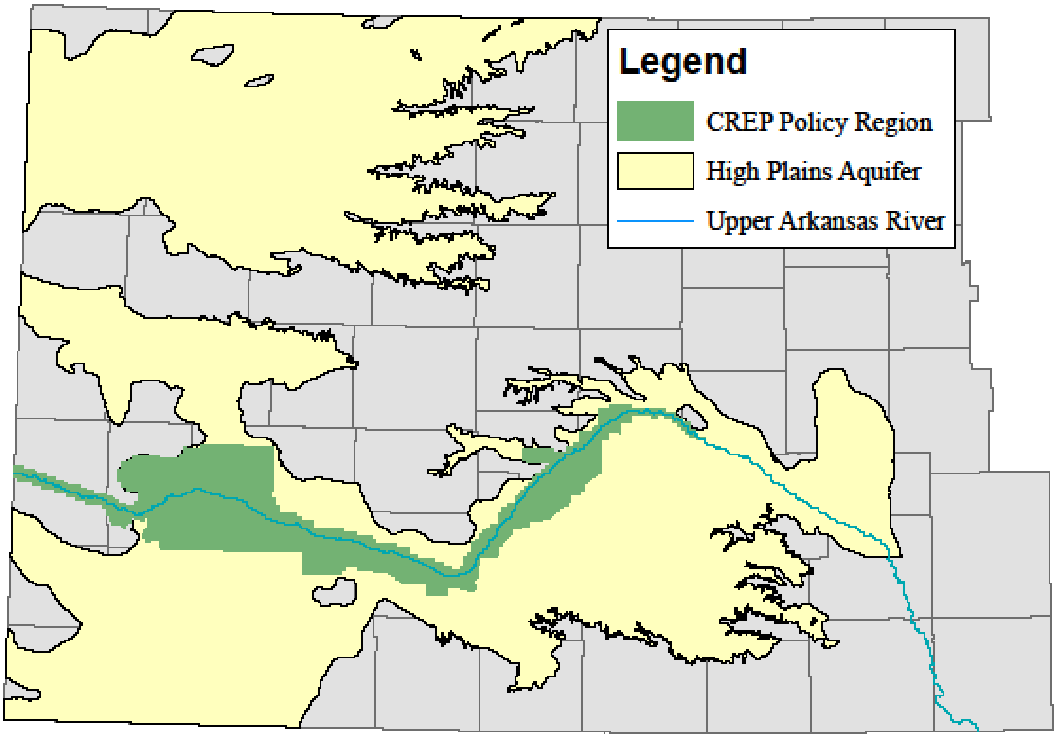

Figure 4.2: The High Plains Aquifer and CREP policy region

Table 4.1: Upper Arkansas River CREP enrollment statistics

Year	# of Water Rights Enrolled	Acres Enrolled	AF Enrolled
2008	63	8,794	16,477
2009	10	1,768	3,213
2010	6	1,187	2,023
2011	5	680	1,311
2012	22	4,267	7,477
2013	4	320	1,495
2014	0	0	0
2015	14	1,772	2,918
2016	10	1,194	2,307
2017	4	407	600
2018	7	2,090	2,338
Total	145	22,479	40,158

Note: Data was provided by Steve Frost. As a reference, a total of 749,312.9 acres were authorized for irrigation in the CREP region as of 2008.

Chapter 5: Data for Analysis of CREP

In 1988, Kansas required reporting of water use for all non-domestic wells (Sophocleous 2012). Consequently, the Kansas Department of Agriculture and the Kansas Geological Survey provide a highly detailed water rights database, called the Water Information Management Analysis System (WIMAS). Most data provided by WIMAS is recorded at the unique water right, well, or place of use level, or at some unique combination of the three. Table 5.1 provides the unit of observation for each of the variables used in the analysis. The water use data, reported each year in total acre-feet used, is most complete starting in 1996 and is available until 2016. Thus, the water use analysis is conducted for those years. If a unique well is associated with multiple water rights, water use can be recorded one of two ways. It can be recorded all in one report which aggregates water use across all rights, or in separate reports that record the water use of each unique water right-well combination (Wilson et al. 2005). WIMAS also identifies the total and net acres and AF authorized for a particular water right. If multiple water rights overlap for a place of use, net acreage or AF authorized are positive for the most senior right. For most water use reports, WIMAS also provides information about which crop types were planted each year, including single crops and various crop combinations, as well as the irrigation system used each year. Finally, for most wells, data is provided on depth to groundwater, measured as the distance in feet from ground-level to the top of the aquifer.

Information about which water rights have enrolled in CREP and their associated right dismissal dates is provided by the Kansas Department of Agriculture. This information includes a list of water rights that enrolled in CREP from 2008 to

2018, the date on which each water right file was dismissed and how many acre-feet of authorized use were associated with the retired right. The Kansas Department of Agriculture have also provided a shapefile showing the CREP policy region. The shapefile is used to identify which water rights are eligible for CREP and what soil tier each right is associated with. Rental rates from the FSA and one-time payments from the state of Kansas are identified using brochures marketing the program to farmers.

Table 5.1: Description and Sources of Data

Variable	Unit of Observation	Source
WR	One to Many WRs per Well	WIMAS
Well	One to Many Wells per WR	WIMAS
POU (QQ section)	One to Many POUs per WR	WIMAS
Water Use	Well or WR/Well combination	WIMAS
Crop Type	Well or WR/Well combination	WIMAS
Irrigation System	Well or WR/Well combination	WIMAS
Depth to Groundwater	Well	WIMAS
Total and Net AF Authorized	WR or WR/Well combination	WIMAS
Total and Net Acres Authorized	WR	WIMAS
GMD	WR	WIMAS
Right Dismissal Dates	WR	DOA
Rental Rates	HUC8	DOA
Geospatial Data	Format	Source
POU (QQ Section)	Shapefile	BLM
CREP region	Shapefile	DOA
Soil Tier	Shapefile	DOA
Soil Data	Raster	SSURGO
Saturated Thickness	Raster	NHD
Abbreviations		
WIMAS	Water Information Management Analysis System	
DOA	Kansas Department of Agriculture	
WR	Water Right	
POU	Place of Use	
QQ	Quarter-Quarter Section (40 acres)	
GMD	Groundwater Management District	
BLM	Bureau of Land Management	
SSURGO	Soil Survey Geographic Database from the US Department of Agriculture	
NHD	National Hydrography Dataset from US Geological Survey	

Data is also compiled from various other sources. Spatial soil data is available in raster format from the Soil Survey Geographic Database (SSURGO) from the USDA. Included in the analysis are the non-irrigated capability class (NICC), available water storage (0-150 cm), land slope (measured in degrees), national commodity crop productivity index (NCCPI), and the wind erosion index (WEI). Wind erodibility is an important determinant in Kansas' process for categorizing soil tiers. Data for saturated thickness in 2009 comes from the United States Geological Survey (USGS) National Hydrography dataset and a boundary file identifying HUC 8-digit watersheds is from the KWO. Rental rates offered by the FSA to each water right are determined by which HUC 8-digit watershed it is located in, the particular year of the observation, and which irrigation system it had at the beginning of the program. Rates from the state of Kansas are determined by soil tier and the year of the observation.

Measuring the effect of enrollment in CREP on water use requires a unit of observation that identifies the total water use associated with a particular plot of land. This unit of observation must also have an identifiable amount of acreage and quantity of authorized water use retired under CREP in any given year. Because the relationships between water rights, wells and places of use can be complex, I create a unit of observation that I call water usage units to analyze the effects of CREP on water use. Usage units often correspond with individual water rights, but in many cases are composed of a combination of multiple rights, wells and places of use. I describe them in more detail in the next paragraph. Enrollment decisions, on the other hand, are made at the water right level and I therefore model them that way.

Consequently, I generate control variables separately for both the usage unit and water right levels.

Water usage units are needed because enrollments in CREP and water use are recorded at different units of observations. Farmers enroll individual water rights in CREP, but record their water use at the well level. This poses a problem because water use cannot always be identified at the unique water right level and the amount of acreage or authorized use enrolled in CREP cannot always be identified at the well level. Because water use reports sometimes aggregate use for individual wells attached to several water rights, water use cannot always be identified for a water right. Further, authorized acreage or authorized use is associated with water rights and not with wells. If multiple wells are associated with a unique water right, an amount of acreage or authorized use enrolled in CREP cannot be assigned to an individual well. Finally, it is desirable to obtain the total water use for entire plots of land, which are identified by places of use. Even if water use can be identified for a water right, this may not reflect total water use for a plot of land if multiple water rights are associated with it. Consequently, I create water usage units, which can be defined as the smallest unit of non-overlapping combinations of water rights, points of diversion and places of use.

Figure 5.1 provides an example that helps clarify how water usage units are created. In the figure, wells 1 and 2 are combined into a single water usage unit. The two wells have overlapping places of use and are both associated with water right 1. Thus, the annual water use for water usage unit 1 is defined as the sum of water use from wells 1 and 2. Well 3 is only associated with water right 3 and place of use 3, and thus is a separate water usage unit. However, suppose well 2 supplies place of use 3 in addition to place of use 2. In this case all three wells are combined into one water usage unit, even though there would still be no direct overlap between wells 1 and 3. By creating water usage units, the total water used for a particular defined plot of land can be identified. Further, any retired land is completely included in a particular usage unit. This allows for an accurate measurement of how the retirement of a portion of a water usage unit affects water use. Annual water use (both total and per acre), net acres authorized, total retired acre-feet and acreage through CREP are all calculated at the water usage unit level.

In contrast to water use decisions, enrollment decisions in CREP are best analyzed at the water right level. Thus, variables are constructed at the usage unit and water right levels to use in the water use and enrollment regression analyses, respectively. Because soil and saturated thickness data is distributed continuously in raster format, it is used to create weighted averages at the water right and water usage unit levels. Places of use for water rights and their associated authorized acreage are recorded at the quarter-quarter section level of the public land system survey (PLSS) from the Bureau of Land Management. Because of this, soil and saturated thickness data is obtained for the centroid of each quarter-quarter section. I then create weights based on the proportion of each water unit or water right taken up by each quarter-quarter section.[2] I then average soil characteristics accordingly to get soil and saturated thickness data at the water unit and right levels. Because the NICC is a

[2] Only the PLSS section grid is publicly available. To create a shapefile of quarter-quarter sections, I divide the PLSS section grid into sixteenths. Then using the centroids of each quarter-quarter section, I identify the soil characteristics and saturated thickness of each.

categorical variable, I use the mode for a particular water unit or right rather than weighted averages. Finally, for well depths, I use the average depth to water for the most recent measurements across all wells associated with each usage unit or right.

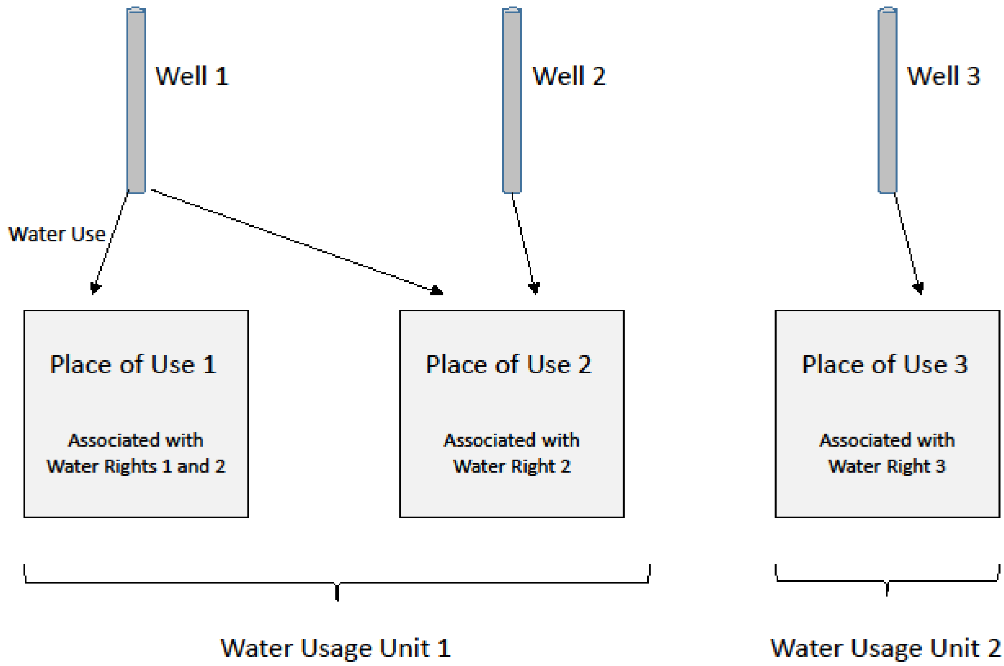

Figure 5.1: Relationship between water rights, places of use, wells and water usage units

Note: The figure shows an example of relationships between water rights, places of use and well to illustrate the need for water usage units. Water use is recorded for each well, either aggregated across all associated water rights, or for each individual water right. Because water use is sometimes aggregated, you cannot know water use for each water right uniquely. In general, each well can be associated with several places of use and water rights. Water rights can each have places of use and wells that overlap. Water usage units are defined as mutually exclusive groups of well-water right-place of use combinations such that there is no overlap in any of the three elements.

Some variables are only included in the enrollment analysis. This includes crops grown and irrigation system used. Because usage units can consist of many water rights and wells, there is not an intuitive way to associate one particular type of crop or irrigation system to usage units generally. To determine the crop most associated with a water right, dummy variables are first created for three crop types at the water right level for each year. Then, the mode across all pre-policy years is used to determine which crop was grown most often. Irrigation systems for a water right are specified as the most recent irrigation system used before the program. Irrigation systems can be a flood, center pivot or Low Energy Precision Application (LEPA) center pivot system, where each is assigned a dummy variable and flood is the default category.

Tables 5.2 and 5.3 provide sample statistics for each of the variables generated for the analysis, at the usage unit and water right levels, respectively. Means and standard deviations for each variable are shown for observations either inside or outside the CREP region (see figure 4.2). Note that crop choice and irrigation system are identifiable at the water right level, but not easily aggregated to the usage unit level. However, neither of these factors have a significant impact on enrollment, as we will see. In the CREP region, there are 3,187 senior water rights with positive net authorized acreage, associated with 2,448 unique water usage units. Averages of most variables are comparable between usage units and water rights. The notable exception is net acres authorized. This reflects the fact that usage units may be made up of multiple water rights with positive net authorized acreage. Groundwater users in the CREP region are representative of other groundwater users in the state for some variables. Saturated thickness, depth to groundwater, and general soil quality (measured as NCCPI) are similar inside and outside the CREP policy region. However, the region is made up of higher sloped land and more erodible soils, which is unsurprising as the region was targeted in part to reduce erosion.

Table 5.2: Summary Statistics of Water Rights

	Non-CREP region rights		CREP region rights	
	Mean	SD	Mean	SD
Avg Water Use per Acre (of associated unit)	0.690	0.829	0.893	0.497
Wind Erosion Index	62.12	37.23	97.52	55.00
Available Water Storage (mm)	230.2	99.56	211.5	66.41
NCCPI	0.313	0.152	0.287	0.117
Slope Gradient	1.571	1.800	3.574	4.413
NICC	2.504	0.873	3.381	1.668
Missing NICC	0.209	0.406	0.101	0.301
Saturated Thickness (ft)	116.0	86.64	129.7	81.75
Missing Sat Thickness	0.186	0.390	0.0228	0.149
Corn Grower	0.535	0.342	0.384	0.331
Alfalfa Grower	0.0752	0.203	0.245	0.333
Wheat Grower	0.164	0.260	0.170	0.257
Missing Crop Data	0.149	0.356	0.141	0.348
Flood	0.162	0.369	0.132	0.338
Center Pivot	0.176	0.381	0.165	0.372
Center Pivot - LEPA	0.615	0.487	0.682	0.466
Missing Irrigation System	0.178	0.382	0.177	0.381
Depth to Water (ft)	97.45	107.8	102.5	89.08
Missing Depth	0.460	0.498	0.476	0.500
Net Acres Authorized	220.6	221.0	235.8	222.5
Number of Water Rights	17,048		3,187	

Note: The table includes data from 2008 for all senior water rights inside and outside the CREP region.

Table 5.3: Summary Statistics at Usage Unit Level

	Non-CREP region units		CREP region units	
	Mean	SD	Mean	SD
Avg Water Use per Acre	0.721	0.876	0.931	0.517
Wind Erosion Index	63.02	37.24	95.07	53.71
Available Water Storage (mm)	232.3	97.03	214.4	67.10
NCCPI	0.348	0.147	0.317	0.122
Slope Gradient	1.615	1.785	3.380	4.253
NICC	2.492	0.864	3.257	1.625
Missing NICC	0.190	0.393	0.0895	0.285
Saturated Thickness (ft)	114.6	83.63	126.6	81.41
Missing Sat Thickness	0.173	0.378	0.0155	0.124
Depth to Water (ft)	98.99	108.2	103.9	88.80
Missing Depth	0.393	0.489	0.382	0.486
Net Acres Authorized	265.7	296.6	306.1	359.2
Number of Water Units	14,238		2,448	

Note: The table includes data from 2008 for all water units with positive net authorized acreage inside and outside the CREP region.

Chapter 6: Methods Used in CREP Analysis

6.1. Effects of CREP on Water Use

The first part of the analysis determines the water use savings that can be directly attributed to the UAR CREP. Using a panel of annual water use of water usage units, equation 6.1 describes the first specification used to estimate the policy impact. In equation 6.1, $\mathrm{w_{it}}$ is the water use per acre of water usage unit i in year t. The variable $\mathrm{R_{it}}$ designates the total acre-feet per acre or the proportion of total acreage retired for water unit i in a particular year. Additionally, $\mathrm{\mu_i}$ is a usage unit-level fixed effect, $\mathrm{\lambda_t}$ are year fixed effects, $\mathrm{\gamma_{it}}$ are GMD-year fixed effects, and $\mathrm{e_{it}}$ is a random component. Water use does not cease entirely when rights are first enrolled in CREP. Small levels of irrigation are allowed for the first two years after enrollment in order to establish conservation crops. The variable $\mathrm{E_{it}}$ measures the acre-feet per acre or proportion of total acreage of a water unit that is enrolled in CREP but has not yet been required to cease irrigation completely. Once irrigation must be stopped entirely, $\mathrm{R_{it}}$ is positive and $\mathrm{E_{it}}$ equals zero.

(6.1) $$w_{it} = E_{it}\alpha_E + R_{it}\alpha_R + \mu_i + \lambda_t + \gamma_{it} + e_{it}$$

Unit-level fixed effects control for any time-invariant influences on water use. Further, year fixed effects and GMD-year fixed effects control for overall and region-specific time-varying influences on water use. However, an important identifying assumption must be made for the specification in equation 6.1 to consistently estimate the marginal impact of CREP on water use. The year and GMD-year fixed effects λ_t and γ_{it} must represent the counterfactual trends in water use for usage units that enroll acreage in CREP in the years after acreage is enrolled. This requires that units that enroll in CREP (now called enrolled units) have similar water use trends to those units that don't enroll (unenrolled units). This assumption is likely to fail if equation 6.1 is estimated using a sample that includes all water usage units in the CREP region. For example, suppose enrolled units have worse soil quality on average than unenrolled units. Farms with different soil quality may respond to annual fluctuations in rainfall or changes in crop prices differently, or may have different long term trends in water use in general. Parallel trends of water use for enrolled and unenrolled units in pre-policy years may provide a useful indicator of whether a simple fixed effects model is adequate. However, pre-policy parallel trends may not perfectly predict differences in expected water use between enrolled and unenrolled units in the policy period. For example, enrolled farmers who anticipate decreasing water use a few years in the future may use a high amount of water until then.

If unenrolled units do not serve as a viable counterfactual, pre-regression matching can be useful to balance the sample before running a fixed effects regression. Matching samples before using panel regression techniques has become increasingly common in the environmental and resource economics literature (Jones and Lewis 2015). Ferraro and Miranda (2017) compare the performance of panel models for several non-experimental panel data designs with results from a randomized control trial of a household water conservation intervention. They find that fixed effects models combined with pre-regression matching designs perform considerably better than fixed effects without matching. They claim that matching renders several assumptions needed for identification of fixed effects more plausible.

Such assumptions include common response to shocks and homogenous treatment effects.

Due to the likely presence of sample selection, a matched sample is created prior to estimating the regression specified in equation 6.1. A matched control sample is created by pairing each enrolled unit with a comparable unenrolled unit either inside or outside the UAR CREP region. The matched sample is created using one-to-one covariate matching without replacement, with 1 standard deviation calipers for all unit-level covariates. Ferraro and Miranda (2017) find that covariate matching using calipers leads to estimates that very closely approximate their experimental results and that outperform other matching approaches. Covariate balance and parallel trends are then examined. Finally, fixed effects regressions are estimated using the matched sample. As a robustness check, a matched sample is also generated using propensity scores. A probit regression is run with all usage units in the CREP region to determine the propensity of being an enrolled unit. Propensity scores are then assigned to all unenrolled units both inside and outside the CREP region and enrolled units are matched to unenrolled units with the closest propensity scores. This second matched sample is then used to estimate fixed effects regressions as well. Caliper matching is preferred due to better covariate balance and closer pre-policy trends, but results are very similar for both approaches.

Even with a matched sample, equation 6.1 may fail to estimate the policy effect if water users change their behavior after the program is initiated. Once the program is announced, some farmers who use little water may want to retire their water rights. Because the program limits enrollments to intensive water users, these farmers will not be eligible at the time of program announcement. Thus, they may increase their water use for the few years after program announcement so that they satisfy its eligibility requirements. If this phenomenon is common, it could make the policy effect appear artificially large. Equation 6.2 tests for this concern. The variable A_{it} indicates for enrolled units how much they will eventually enroll, once the program is announced in 2007. For each enrolled unit, the variable is positive starting in 2007 and zero once the unit actually enrolls acreage in CREP.

(6.2) $$w_{it} = A_{it}\alpha_A + E_{it}\alpha_E + R_{it}\alpha_R + \mu_i + \lambda_t + \gamma_{it} + e_{it}$$

Because enrollments in CREP occur over time, dynamic sample selection may also be a concern. The specification in equation 6.3 provides a simple approach that accounts for the possibility of dynamic sample selection. If usage units that enroll acreage in later years have different water use trends than those that enroll land early, the estimated marginal effects of CREP could be biased. As seen in table 4.1, enrollments in the program highly corresponded with increases in program rental rates. In the study period, only the price increase in 2012 has had adequate time to observe full right retirements. Thus, I split enrolled units into early and late enrollments, depending on whether they enrolled acreage before or after 2012. Because each enrolled unit is matched with an unenrolled unit, I classify all unenrolled units based on the classification of its enrolled counterpart. In equation 6.3, I include interactions between year dummies or GMD-year dummies and a dummy for being a late enrollment L_i. Classifying enrollments based on time of enrollment allows for differential responses to shocks between the two groups.

(6.3) $$w_{it} = A_{it}\alpha_A + E_{it}\alpha_E + R_{it}\alpha_R + \mu_i + \lambda_t + \gamma_{it} + L_i\lambda_{Lt} + L_i\gamma_{Lit} + e_{it}$$

6.2. Targeting for Water Use

Voluntary incentive schemes often come up short in achieving their intended policy goals due to unintended behavior of recipients. Consequently, measuring the water use reduction attributable to CREP is a crucial part of evaluating its performance. However, even if CREP leads to significant water savings for those that enroll, it may cost federal and state agencies more than is necessary. This section outlines the conceptual problem faced by a government agency seeking a cost-effective water rights retirement program.

The approach used to evaluate the cost-effectiveness of retirement policies is motivated with a brief conceptual model. Suppose a water rights retirement program similar to CREP offers per-acre incentives to farmers willing to retire their water rights. Assume for now that the incentive rates offered do not increase over time. We will consider the implications of rate increases below. Each farmer has a value π_j per acre for his water right j and will have an annual per-acre water use w_j if he retains his water right.[3] If a farmer retires his water right, his annual water use then equals zero. Further, assume that farmers have static expectations of future returns, meaning that they expect the value of their water rights to remain constant over time.[4] Thus once a farmer stands to receive at least π_j in total incentive payments per acre, he will retire his water right and there will be a savings of w_j for each acre that farmer retires.

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[3] In CREP, the farmer can return to dryland agriculture after 15 years. For CREP, the value of a water right is simply the difference in profits received between retaining and retiring the right.

[4] Relaxing this assumption could complicate the model considerably (Plantinga and Lewis 2014). It is likely that the value of water rights will remain relatively constant over a short time period.

Now consider the manager's problem in equation 6.4, given the above decision rule for farmers. Suppose the manager of the retirement program has perfect information, such that he can perfectly predict water right values and water use for each farmer. He will maximize water savings, equal to the sum of water savings from all enrolled farmers, subject to a budget constraint C. Water savings for a particular farmer's water right is positive if the manager offers more than the value of the farmer's water right. Thus the indicator function in the equation below will equal one if the manager makes such an offer. With perfect knowledge, the manager will pay no more than is necessary, so that incentives paid to a particular water right per acre retired are equal to the value of the water right per acre π_j. Given that a water right is enrolled, the water savings attributable to a given farmer equals his per-acre water use w_j times the amount of acres associated with his water right, A_j. Total costs of the program equal the total incentives paid per acre θ_j for right j times the acres associated with that right.

(6.4) $$\max_{\theta_j \in \{0, \pi_j\}, \forall j} \sum_j w_j A_j \mathbb{1}(\theta_j > \pi_j) \;\; s.t. \; \sum_j \theta_j A_j \leq C$$

The left panel of figure 6.1 helps to illustrate the manager's targeting problem. Farmers are distributed along two dimensions, their future annual water use and their future profits. A manager with perfect foresight would want to first target individuals with low π_j / w_j. As the amount of total water savings increases, the manager will need to pay farmers with a higher ratio of profits to water savings. In other words, the marginal cost of water savings will increase as the water goal increases. A marginal cost of water savings function $c(W)$ can be derived by ordering all farmers based on their value of π_j / w_j from smallest to largest. The right panel of figure 6.1 depicts this function. The manager can simply pay incentives to individuals starting with those with the lowest costs of water savings, until the budget constraint is met. In the figure W^* represents the amount of water savings when the budget constraint is reached. The total cost with perfect targeting is then the area under the supply curve and the cost per unit saved is defined formally as $\frac{\int_0^{W^*} c(W)}{W^*}$. This is the total cost divided by the total water savings of the program.

Of course, such an ideal policy where the manager has perfect foresight is not possible. The manager cannot perfectly predict the future water use and value associated with each water right. However, the manager can use various techniques to approach the perfect policy. Consider two targeting elements of the existing CREP policy. The first is its eligibility requirements and the second is to increase incentive rates over time. CREP only pays incentives for farmers with past water use above its eligibility requirements. Assume for now that past water use is a good proxy for a farmer's future water use if he retains his water right. As before, a farmer will enroll his water right in CREP if his water right is less valuable than the incentive rate paid to him. The shaded region in the left panel of figure 6.1 shows the farmers that will enroll in CREP for a given incentive rate θ_j and eligibility requirement (simplified here). By only allowing farmers with past water use above a certain level, CREP avoids paying high costs for low water savings. Second, by increasing rates over time, CREP is able to target progressively more valuable water rights. When the horizontal line in the left panel of figure 6.1 increases over time, farmers with higher opportunity costs then enroll in the program. By rolling out the policy in this way, a policy can target farmers based on unobservable differences in the value of water rights.

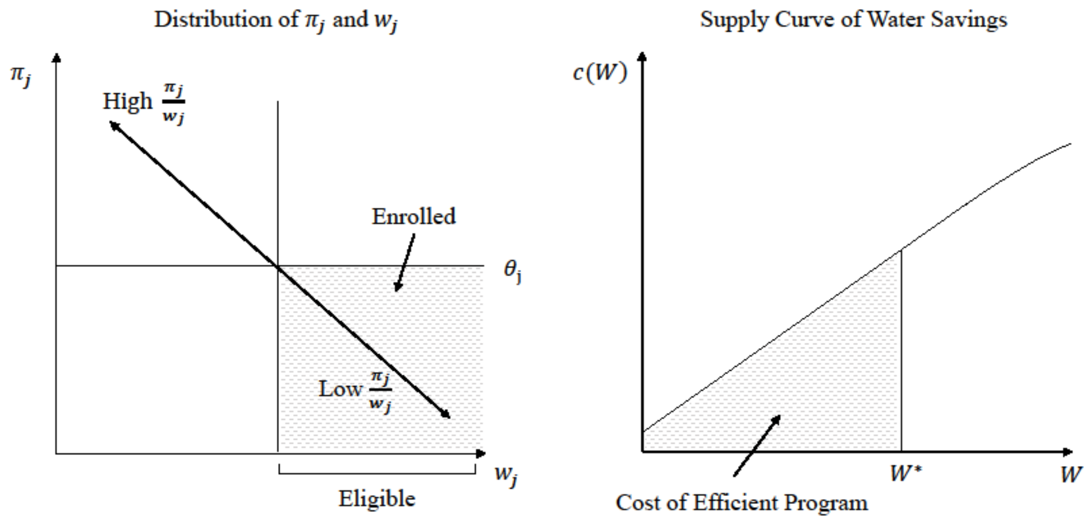

Figure 6.1: Distribution of profits and water use and optimal targeting

Note: The left panel of the figure shows which water rights will enroll in a program similar to CREP, given some distribution of water right values π_j and water use w_j. If a water manager could observe each value and use associated with each water right, he could rank them and create the water savings supply curve on the right panel. He could then achieve the most cost-effective water savings by paying farmers with the least costly water savings until some budget constraint was met, providing a total water savings of W^*.

There are some reasons why each of these targeting approaches could have adverse consequences. First, an eligibility requirement based on past water use might incentivize farmers to ramp up water use prior to enrollment. This is examined with the fixed effects regressions of water use. Second, if a policy keeps raising incentives over time, the farmer decision rule described above may not hold. Instead, savvy farmers may delay their decision to enroll until the next incentive rate hike. Such a forward looking farmer would be faced with the following decision. If he enrolls now, he is guaranteed 15 years of payments. If he waits to enroll, there are two possibilities. He can farm for a few more years, then enroll once a higher incentive rate is offered. However, if the program cap is met before the offered rate increases, he will lose his chance to enroll and must continue to use his land for farming. If there is a significant chance that the program will end before the next rate hike, then only those farmers with almost nothing to gain by enrolling today will delay their decisions. For CREP, there is a relatively small cap in total acreage enrolled and gaps of several years between rate hikes, so that farmers take a considerable risk by delaying their decisions.. Thus we can reasonably assume that the farmer decision rule described above holds and that farmers do not delay decisions in anticipation of rate increases for programs similar to CREP. For a larger scale program, anticipation may pose a greater concern. A brief discussion of incentive rate hikes as applied to larger policies is provided in the next chapter.

In addition to the targeting elements used in CREP, the following are some ways that similar water rights retirement programs could increase their cost-effectiveness. First, a policy that pays based on actual water use is more suited to target individuals with the lowest profit to savings ratio. To prevent farmers from increasing water use to improve their incentive rates, such a policy could base rates on water use from before policy initiation. Second, as can be seen in the left panel of figure 6.1, for a given water use, the profit to savings ratio can vary substantially. Ideally, a targeting approach is able to distinguish between high water users with high and low future profits, so that the latter are not paid more than necessary. The next section outlines an approach to assess the cost-effectiveness of different incentive schemes in the presence of asymmetric information. It assesses policies that use some of the targeting approaches outlined in this section. This includes incentive rate increases, incentives based on prior water use and policies that pay different incentives based on predicted future profits and water use.

6.3. Evaluating Cost-Effectiveness of Water Rights Retirement Policies

This section details the approach taken in this study for evaluating the cost-effectiveness of alternative incentive-based water rights retirement policies. First, enrollment dates from the UAR CREP are used to estimate a panel binary choice model of enrollment decisions. The model includes incentive rates and farm characteristics as covariates. Second, estimated coefficients from the CREP enrollment regression are used to simulate farmer decisions outside of the CREP policy region. Water use is known for all individuals outside of the CREP region for the years in which the simulations are done. Thus, counterfactual water savings are calculated for those farmers who enroll in each policy simulation. Results from the enrollment regression are then used to simulate farmer decisions for six incentive-based policies. Included in the incentive-based policies are policies that pay a constant rate per acre; policies that pay a constant rate per AF of prior water use; and efficient targeting schemes that pay different rates to different groups. Each of these types of policies are simulated with and without incentive rollouts. The policies are then assessed and compared based on a measure of absolute cost-effectiveness. The process of using econometric estimation to model land use decisions and subsequently simulating farmer responses to incentives is sometimes called an econometric-based landscape simulation (Plantinga and Lewis 2014).

First, enrollment decisions are modeled. A farmer is assumed to retire his water right if the incentives provided by CREP are more valuable than the future profitability of his plot when irrigated. Equation 6.5 shows the present value of future per acre profits received from the plot associated with water right j in year t if it is not enrolled, π_{jt0}. This depends on farm characteristics x_j and random components ζ_j and e_{jt0}. The term ζ_j is a random effect that represents a time-invariant component of future profits observable to the farmer but not the econometrician. Equation 6.6 describes the net returns π_{jt1} from enrolling in CREP. The farmer will then receive a net present value payment of θ_{jt} per acre offered to right j in year t. The farmer may also continue to make profits via dryland farming after 15 years, which depends on the vector of farmer characteristics.

(6.5) $\pi_{jt0} = x_j'\alpha + \zeta_j + e_{jt0}$

(6.6) $\pi_{jt1} = \theta_{jt}\kappa + x_j'\lambda + e_{jt1}$

The decision to enroll in CREP is then modeled using equation 6.7. A farmer will enroll right j in CREP, where $\mathrm{E_{jt}} = 1$, if $\pi_{jt1} > \pi_{jt0}$ in year t. If the farmer does not enroll in a given year, $\mathrm{E_{jt}} = 0$. To consistently estimate the incentive rate parameter, we must assume that farmers do not delay their enrollment decisions in anticipation of incentive rate increases. This is thought to be reasonable due to reasons discussed in the last section.

(6.7) $\Pr(\mathrm{E_{jt}}) = \Pr(\pi_{jt1} > \pi_{jt0}) = \Pr\left(\theta_{jt}\kappa + x_j'(\lambda - \alpha) - \zeta_j > e_{jt0} - e_{jt1}\right)$

Enrollment is an irreversible decision, so that once a right is retired, it is removed from the sample in subsequent years. Irreversible decisions can be modeled using panel binary choice models or duration models, which model timing decisions (Cameron and Trivedi 2005). After setting $\beta = \lambda - \alpha$ and $\nu_j = -\zeta_j$, equation 6.8 describes a binary choice model to be estimated. The function F is assumed to be a normal or logistic cumulative distribution function, where parameters are estimated using either a probit or logit model.

(6.8) $\Pr(\mathrm{E_{jt}}) = \mathrm{F}(\theta_{jt}\kappa + x_j'\beta + \nu_j)$

Because equation 6.8 will be used to simulate incentive-based policies, it is particularly important for the coefficient of prices to be consistently estimated. This requires that individual-level variation in incentive rates is uncorrelated with other unobserved influences on enrollment decisions. Incentive rates are set by the USDA and the state of Kansas. Variation in rates offered across individuals depend on watershed, soil erodibility and irrigation system. Regional differences in rental rates reflect differences in average temperatures, rainfall and land quality. Such differences are controlled for using regional fixed effects. Further, soil erodibility and irrigation system are explicitly included in the model. This mostly leaves variation in incentives over time to identify κ. Variation over time is also institutionally determined. Increases are similar for most individuals and are considered to be exogenous.

Further, because equation 6.8 is a model of irreversible decisions, the random effects are necessary to consistently estimate κ. As seen in table 4.1, spikes in enrollment coincide mostly with increases in rental rates. When modeling irreversible decisions, a decrease in the enrollment rate over time like that observed can be a result of observed or unobserved heterogeneity. Basically, those water rights with characteristics that lead CREP to be appealing will enroll early. As rights enroll, those with the highest probability of enrolling are gradually removed from the sample, leaving the appearance of a decrease in probability of enrollment over time. When the distribution of unobserved heterogeneity is not of primary interest, unobserved heterogeneity can simply be modeled by parameterizing time (Cameron and Trivedi 2005). However, in this analysis, unobserved heterogeneity must be modeled explicitly. If a time trend was used to model heterogeneity, it would lead to an undesirable property of the simulations. For two decisions occurring in different years but with the same incentive rate, the probability of enrollment assigned to a water right would be different. For different simulations with different levels of enrollments at any given point, this property could generate erroneous probabilities.

Binary choice models are estimated using a panel dataset of enrollment decisions in CREP. Enrollments are categorized by which year a right was dismissed. However, for any rights dismissed past October, the dismissal is attributed to the following year. This is because any announcements of rate increases were implemented in October, so that any enrollments before the announcement received the lower rate and any enrollments after received the higher rate. Each eligible water right is then assigned a present value of incentive payments offered each year based on information from the Kansas Department of Agriculture. All rights retirements from 2008 to 2017 are included in the sample. Only CREP-eligible water units and their associated water rights are included in the sample. Eligibility is determined as any water unit with at least 0.5 AF/acre of average annual use from 1996 through 2007. Because water use is only known for water units, it is not possible to determine which rights would be determined eligible with the available data. However, removing water units with use above an average 0.5 AF/acre is actually stricter than the true requirement, which only requires greater than 0.5 AF/acre in four of six past years. Consequently, a few enrolled units are removed from the sample after this screen. Further, any water rights contained in a water unit with an average water use above 2.5 AF/acre are eliminated. This eliminates any extreme cases in the sample which may be a result of misreporting. Water rights are further screened to avoid enrollment decisions being double counted. If a plot of land that is enrolled in CREP is associated with multiple water rights, both rights must be retired. Unique plots of land are identified by screening for the most senior rights at a particular plot of land.

A sample is also generated for simulations of enrollments of water rights outside of the CREP region. The same screens as with the enrollment regression sample are then made. Only rights with associated usage units with average use above 0.5 AF/acre from 1996 through 2007 are included, corresponding with CREP eligibility requirements. Further, usage units with average use above 2.5 AF/acre are eliminated for the same reasons as above. Finally, as in the enrollment regression, only senior rights are used so that retired land is not double counted. External validity is a potential concern when using estimates from one region to simulate enrollment decisions in another region. In particular, if the enrollment regression was estimated using a sample of water rights completely distinct from the simulated sample of rights, then its coefficients would be unlikely to adequately model enrollment decisions in the outside sample. To limit this sort of extrapolation, the simulations are only conducted in GMD 3 or GMD 5, where most of the CREP region is contained. This limitation also allows for the use of GMD fixed effects in the probit model of enrollment decisions.

In table 6.1 and figure 6.2, I show that the enrollment regression and simulation samples overlap sufficiently so that there is minimal extrapolation. First, table 6.1 shows sample statistics for water rights in the regression and simulation samples. Although mean values are significantly different for some observable characteristics of water rights (t-tests not shown), the range of values overlaps considerably for most observables. This can be judged by observing the 5th and 95th percentiles of each sample. For categorical variables such as irrigation type, mean values provide proportions for which each category is represented in either sample. Second, figure 6.2 depicts the distributions of each of the continuous variables graphically. While for some variables there are parts of distributions that do not overlap, this accounts for a minimal portion of the total distributions, so that extrapolation is of little concern.[5] Even though the similar characteristics of water rights occur in both samples, they are distributed differently. Thus if there is significant unmodeled heterogeneity, external validity could still be a concern. Solon et al. (2015) suggests that a good test for model misspecification is to compare the unweighted regression model with a model estimated with inverse probability weights based on the probability of being selected into the sample. I conduct such a test and it does not lead to substantial differences in estimates. Although concerns about external validity can never be completely eliminated, we can thus be assured that the model used in the next section is reasonably specified.

A series of three simulations of farmer right retirement decisions are then conducted to evaluate the cost-effectiveness of six incentive polices. Each simulation uses the estimated parameters from equation 6.8 to predict farmer decisions in the

[5] I implicitly assume here that comparing distributions of individual characteristics separately is an adequate test of extrapolation.

generated sample outside of the CREP region (see table 6.1) from 2008 through 2017. Table 6.2 below provides a summary of how the three simulations are used. The first simulation, simulation 1, is used to set incentive rates for each of the six incentive-based policies analyzed. Because it only relies on pre-2008 water use, it could be used by policy makers that want to set future incentive rates. Once simulation 1 is conducted, distributions of water savings for a range of incentive rates are calculated for each policy. These distributions are used to estimate water savings supply curves,

Table 6.1: Comparison of Enrollment Regression Sample and Simulation Sample

	Regression Sample			Simulation Sample		
	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile
Avg Water Use per Acre	0.570	1.031	1.733	0.568	1.008	1.605
Wind Erosion Index	48	102.7	250	48	83.98	134
Available Water Storage (mm)	116.7	206.6	317.7	151.4	237.9	321.0
NCCPI	0.115	0.282	0.510	0.177	0.337	0.516
Slope Gradient	0.161	3.914	13.00	0	2.022	6.500
Saturated Thickness (ft)	25.26	133.0	289.3	35.49	164.1	340.9
Missing Sat Thickness	0	0.0214	0	0	0.000697	0
NICC Level 0-2	0	0.476	1	0	0.519	1
NICC Level 3-5	0	0.333	1	0	0.440	1
NICC Level 6-7	0	0.0978	1	0	0.00383	0
Missing NICC	0	0.104	1	0	0.0968	1
Corn Grower	0	0.369	1	0	0.561	1
Alfalfa Grower	0	0.236	0.917	0	0.0716	0.583
Wheat Grower	0	0.128	0.667	0	0.176	0.875
Missing Crop Data	0	0.0974	1	0	0.0590	1
Flood	0	0.0838	1	0	0.0439	0
Center Pivot	0	0.145	1	0	0.191	1
Center Pivot - LEPA	0	0.628	1	0	0.663	1
Missing Irrigation System	0	0.133	1	0	0.0937	1
Depth to Water (ft)	0	55.89	218	0	76.30	300
Missing Depth	0	0.462	1	0	0.419	1
GMD 3	0	0.692	1	0	0.581	1
GMD 5	0	0.285	1	0	0.419	1
Number of Water Rights		2,567			5,741	

Note: The table includes data from 2008 for all senior water rights. The regression and simulation samples include all water rights with pre-2008 average water use above 0.5 AF per acre (to screen for program eligibility) and below 2.5 AF per acre (to screen potentially erroneous measurements).

which are then used to identify the rates for each policy that maximize water savings given a budget constraint. More details are provided below. Simulation 2 then evaluates the performance of the six policy schemes, using the incentive rates determined by simulation 1. This simulation evaluates post-2008 water savings for each policy had it been designed prior to 2008, with incentive rates based on pre-2008 average water use. This simulation is used to calculate distributions of total savings, total number of enrollments, and cost per savings of each policy.

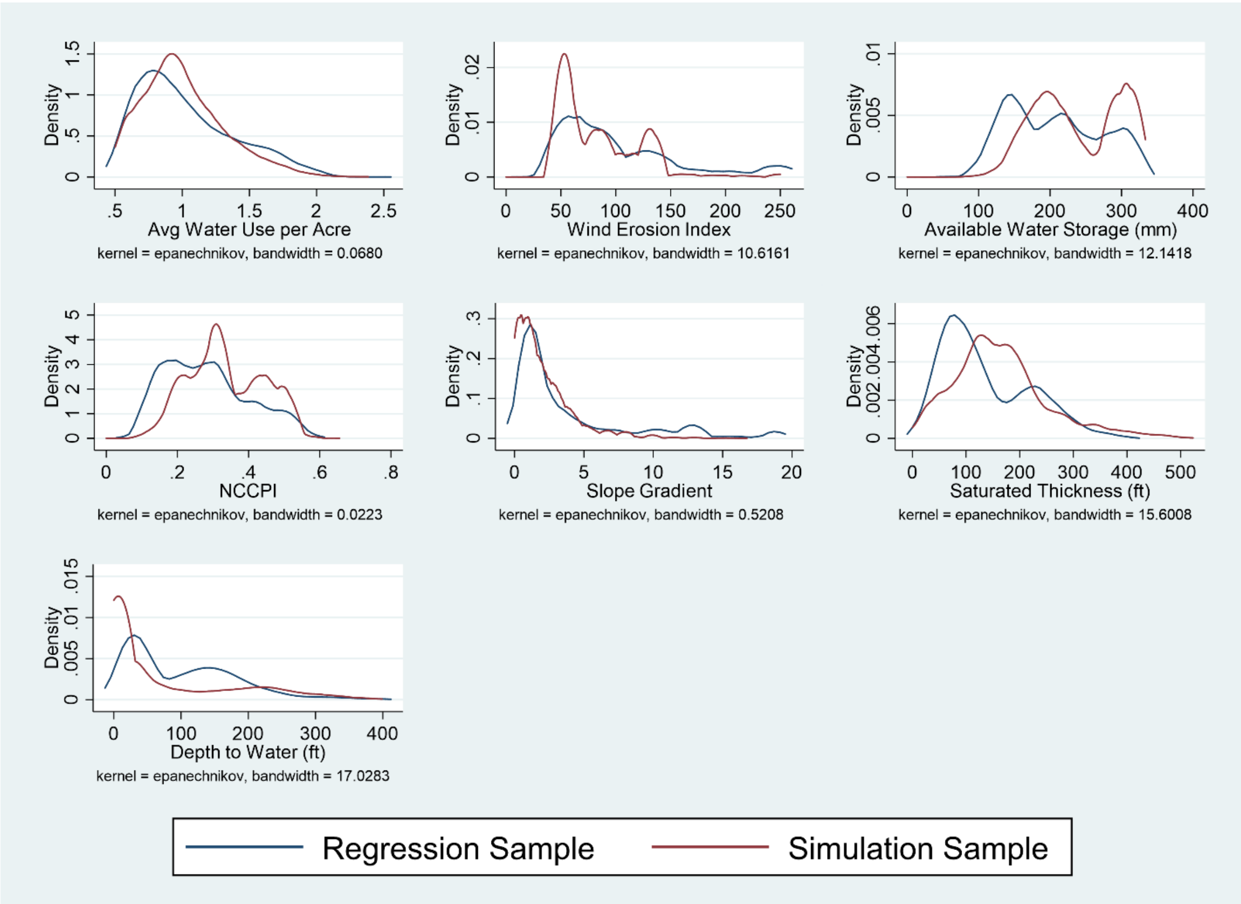

Figure 6.2: Comparison of distributions of continuous variables for regression and simulation samples

Finally, the cost-effectiveness of the six policies is compared using simulation 3. Simulation 3 calculates the cost per savings of a policy that pays farmers their exact opportunity cost for their water right. This calculation serves two purposes. First, the cost per savings of a perfect targeting policy provides a way to compare policies with different levels of average water savings. Second, it measures how costly each policy is compared to a perfect targeting policy. The results of the simulation are used to estimate a supply curve of water savings as in figure 6.1 for incentive rates based on post-2008 water use. The supply curve is used to calculate the cost per savings of the perfect targeting policy. A metric of absolute cost-effectiveness for each policy is then calculated as the ratio of cost per savings for each incentive policy and the perfect targeting policy. Ultimately, only simulation 1 can be used by policy makers who want to design new programs. However, simulations 2 and 3 are used in this study to evaluate the performance of potential policies. They take advantage of real water use data to calculate water savings for counterfactual policies conducted from 2008 through 2017.

Six different policies are investigated in the simulations of farmer enrollment decisions, summarized in table 6.3 below. First, I look at policies that set incentive rates based on total acreage retired. The first policy sets a per-acre incentive rate that remains constant across the entire policy period of 2008 through 2017. The second policy increases rates over time. Similarly to CREP, rates are increased by $200 per acre in 2012 and by $400 per acre in 2016. Thus, this incentive scheme can be thought of as a “synthetic CREP” policy. Next, two policies are simulated that pay incentives based on pre-2008 water use. The first policy uses a per-use rate that is constant across the policy period. For the second policy, rates increase by $200 per AF in 2012 and by $300 per AF in 2016. Finally, a policy is used that assigns different per AF rates to different farmers based on a combination of predicted profitability and past water use.

Table 6.2: Overview of Simulations Used in Cost-Effectiveness Calculations

Simulation number	Simulation Purpose	Data Used for Setting Incentives	Data Used for Calculating Savings	Can be used in determining future policies?
1	Estimate water savings supply curves to set optimal incentive rates for 6 incentive-based policies	Avg annual water use from 1996-2007	Avg annual water use from 1996-2007	Yes
2	Calculate cost per savings given optimal incentive rates from simulation 1	Avg annual water use from 1996-2007	Avg annual water use from 2008-2016	No
3	Estimate water savings supply curve to calculate baseline costs per savings	Avg annual water use from 2008-2016	Avg annual water use from 2008-2016	No

Each simulation uses the estimated parameters from equation 6.8 to predict farmer decisions in the generated sample outside of the CREP region (table 6.1) from 2008 through 2017. Probabilities of enrollment must be generated for each water right in each policy year. Given some per-acre incentive rate, probabilities of enrollment of right j in year t, $\hat{P}_{\mathrm{jt}}$, are created for a given incentive level, corresponding with equation 6.9. If per use incentives are used, they must be multiplied by pre-2008 average per-acre water use for the associated water unit of a right to get a per acre incentive rate. For example, at an incentive rate of $1000/AF, a water right that uses

Table 6.3: Overview of Policies Assessed in Cost-Effectiveness Comparison

Policy Scenario	Payment Type	Rate Increases	Who Is Paid What?
Per Acre (constant)	Payment based on total acreage retired	Same rates offered throughout simulated policy period	All eligible rights get paid same per acre rate in any given year
Per Acre (rollout), "Synthetic CREP"	Payment based on total acreage retired	Rates offered increase by \$200 per acre in 2012 and \$400 per acre in 2016	All eligible rights get paid same per acre rate in any given year
Per AF (constant)	Payment based on avg AF of annual water use from 1996-2007	Same rates offered throughout simulated policy period	All eligible rights get paid same per AF rate in any given year
Per AF (rollout)	Payment based on avg AF of annual water use from 1996-2007	Rates offered increase by \$200 per AF in 2012 and \$300 per AF in 2016	All eligible rights get paid same per AF rate in any given year
Targeted (constant)	Payment based on avg AF of annual water use from 1996-2007	Same rates offered throughout simulated policy period	Each bin of expected profits and past water use is given same per AF rate in any given year
Targeted (rollout)	Payment based on avg AF of annual water use from 1996-2007	Rates offered increase by \$200 per AF in 2012 and \$300 per AF in 2016	Each bin of expected profits and past water use is given same per AF rate in any given year

.5 AF/acre on average from 1996 through 2007, will receive a payment of $\theta_{jt} =$ \$500/acre. The same right-hand side variables used in the enrollment regression are used to predict the probability of enrollment for farmers outside the CREP region for the years 2008 through 2017. In order to generate random effects $\hat{v}_j$, values can be randomly drawn from the estimated distribution of random effects from equation 6.8.

(6.9) $\hat{P}_{\mathrm{jt}} = \mathrm{F}(\theta_{jt}\hat{\kappa} + x_j'\hat{\beta} + \hat{v}_j)$

Enrollment decisions are then determined using Monte Carlo simulations. Each round is conducted as follows. First, every water right in the sample is assigned a random effect, according to the estimated distribution of random effects from equation 6.8. Given each water right's random effect, farmer characteristics, and a given incentive rate, it is assigned a probability of enrollment for each year in the sample. Second, for each water right numbers are drawn for each year from 0 to 1 using a uniform distribution. If the value drawn is less than the generated probability in a particular year for a particular incentive rate, the right retires (Lewis and Plantinga 2007). Once a water right is retired, it remains retired for the remainder of the simulated policy period. The total cost for a given incentive policy is calculated by multiplying the per acre incentive rate offered to each particular individual that enrolls in the year that they enroll by their total acreage enrolled. The water manager is assumed to pay the incentive rate at which that right retires for the remainder of the policy period. A budget constraint for total annual payments of a policy is set such that once passed in a given year, no more enrollments are allowed in any of the following years. The number of total enrollments for a particular round of the simulation is calculated as the number of water rights in the sample that enroll at some point. Finally, the average post-2008 water use for all the enrolled rights are added together to generate a calculation for total water savings. For each incentive rate, this procedure is performed 100 times.

Simulation 1 is used to set per acre incentive rates for each policy. For the per acre incentive that is constant over time, 100 simulations are run for per acre rates ranging from $800 per acre to $2200 per acre in $100 increments. A set of 100 simulations are also run for per acre rates that increase over time. After setting baseline incentive rates starting in 2008 from $800 per acre to $1600 per acre, rates are increased by \$200 in 2012, and by \$400 per acre in 2016. Next, incentives rates are generated for two policies that pay incentives based on pre-2008 water use. Similar simulations are run to set the optimal per AF rates. One rate is constant across the policy period. For a second policy, rates increase by \$200 per AF in 2012 and by \$300 per AF in 2016. Total water savings and total costs are recorded for each simulation, using pre-2008 water use as a proxy for post-2008 water use. Because it is desirable to design a targeting approach that can be used by policy makers, relying on real future water use would make this procedure impossible.

Using the results of each policy simulation, quadratic savings supply regressions are estimated for each policy, with total savings as the dependent variable and 2008 incentive rates as the independent variable. In particular, the results of the simulation are used to estimate equation 6.10. In the equation C_s represents the amount paid per AF of past use in simulation round s. Total annual water use for those enroll in a given simulation round is given by W_s. An error term is given by e_s. Using these savings supply curves, I solve for the incentive rate of each policy that yields the maximum expected water savings given a budget of \$25 million.

(6.10) $W_s = \alpha_0 + \alpha_1 C_s + \alpha_2 C_s^2 + e_s$

Finally, incentives are generated based on a targeting scheme that pays different rates to multiple groups. Again, I examine one policy that pays the same rate over time and one that increases incentive rates two times in the policy period. The creation of targeted incentive rates requires four main steps. First, the sample must be separated into bins based on predicted profits and water use. In equation 6.9, the marginal impact of a particular incentive rate depends on the terms $\theta_{jt}\hat{\kappa}$ and $x_j'\hat{\beta}$, where the incentive rate depends on water use. The marginal impact is not just from the incentive rate because of the nonlinearity of probit models. Further, because of the random component unobservable to the econometrician, only the expected probability of a given individual enrolling can be known. Expected profits from water right j can be defined as $\hat{\pi}_j = x_j'\hat{\beta}$ and predicted water use can be generated based on the regression described above. Both of these values can then be used to split the generated sample into bins of expected profits and water use. Second, simulations are used to estimate supply curves of water savings for each bin for a static policy and one which increases incentive rates twice in the policy period (increases by \$200 per AF in 2012 and by \$300 per AF in 2016). Third, supply curves are used to create efficient targeting policies that set rates specific to each bin. The efficient policies are determined using equation 6.11. The objective is to maximize the savings of expected payments $S_b(\theta_b)$ for a given per-AF incentive rate θ_b for bin b, subject to the budget constraint C. The total cost is the sum across all bins of the per-AF incentive rate for each bin multiplied by the savings at that rate. If $S_b(\theta_b)$ is strictly increasing in θ_b and therefore quasiconcave, then equation 6.11 satisfies theorem 3.6.3 in Sydsæter et al. (2008) for a local maximum to be global. We can then numerically solve for the per AF rates in an efficient targeting policy using a local maximizer.[6]

(6.11) $$\max_{\theta_b, \forall b} \sum_b S_b(\theta_b) \;\; s.t. \;\; \sum_b \theta_b S_b(\theta_b) \leq C$$

The following are the results of the first simulation routine. The per acre incentive policy that remains constant over the entire period is set at a rate of \$1,754

[6] The fmincon function in Matlab is used to solve this problem.

per acre. Next, the per acre rollout policy sets an initial incentive rate of $1,552 per acre in 2008, then increases to $1,752 in 2012 and to $2,152 in 2016. Next are policies that set incentives based on pre-2008 water use. The constant policy sets a rate of $1,388 per AF of average pre-2008 water use. The rollout policy sets a rate of $1200 per AF of average pre-2008 use in 2008, then increases to $1400 per AF in 2012, and to $1700 per AF in 2016. Finally, incentive rates are set for the policy that offers different incentive rates to different farmers based on average pre-2008 water use. Because of the small number of enrollments in simulations, supply curves cannot be reliably estimated for a large number of bins. Thus only two bins were used for the simulation in this analysis. However, in applications with a large number of enrollments, the bin technique could potentially provide much more substantial gains in efficiency.

Simulation 2 is then used to evaluate the performance of the incentive rates set using simulation 1. It does this by taking advantage of data from 2008 to 2017 to test the performance of incentive rates had they been set in 2008 using data from 1996 through 2007. Unlike simulation 1, simulation 2 does not require multiple steps. It simply runs enrollment simulations for each policy approach and then calculates statistics based on actual behavior of farms that enroll in each simulation run. Then the distributions of total savings, total number of enrollments, and cost per savings of each of the six incentive designs are calculated.

To compare the cost-effectiveness of the six incentive-based policies from simulation 2, results for each policy is compared with results from simulation 3, which sets incentive rates based on future water use. Results from simulation 3 are used to estimate an inverse supply curve of water savings for a policy that perfectly targets rights. The supply curve is then used as a baseline to assess the cost-effectiveness of alternative incentive-based policies. Per-acre incentive rates are first created for each individual water right in the simulation sample. Incentives are generated by multiplying post-2008 average per-acre water use for the associated water unit of a right by per-use incentive rates. For example, at an incentive rate of \$900/AF, a water right that uses .5 AF/acre on average from 2008 through 2016, will receive a payment of $\theta_{jt} =$ \$450/acre. Incentive rates here are constant across time, so that the subscript t is superfluous. Once incentive rates are generated, probabilities of enrollment are generated as with other simulations, using results from equation 6.8. Probabilities are generated for incentive rates ranging from \$500/AF to \$1400/AF in \$100 increments and the simulation routine described above is used to generate sample statistics for policies at each incentive rate.

An inverse supply curve of water savings is then estimated using the results of the perfect foresight simulation. In particular, the results of the simulation are used to estimate equation 6.12. In the equation C_s represents the per AF incentive rate, or the cost per AF paid for simulation round s. Total water savings of a given simulation round is given by W_s. This curve is used to calculate the cost-effectiveness of a policy that targets each individual perfectly. Total costs of the perfect targeting policy are calculated by taking the integral under the supply curve for a given water savings level, as shown in the right panel of figure 6.1. Cost per savings of the perfect targeting policy is then calculated as the total cost divided by total water savings.

(6.12) $C_s = \gamma_0 + \gamma_1 W_s + \gamma_2 W_s^2 + e_s$

Once the supply curve of water savings for a perfect targeting policy is generated, it can be used as a baseline to measure the absolute cost-effectiveness of more plausible incentive schemes.[7] A similar simulation routine as described above is used to calculate water savings, total costs, and total enrollments for six incentive-based policies. These policies set incentive rates based on acreage enrolled and prior water use, either uniform or differentiated for different water rights. Each type of policy can have incentive rollouts or can remain constant over time.

[7] Lewis et al. (2011) use a similar approach but here the cost-effectiveness of the optimal policy is obtained differently.

Chapter 7: Results of CREP Analysis

7.1. Fixed Effects

This section provides regression results measuring the water savings attributable to enrollments in CREP. Water use trends and farmer characteristics are compared between enrolled and unenrolled units in the CREP region. These comparisons motivate the need to estimate water use regressions using a matched sample. Then, fixed effects regressions using the matched sample are estimated to assess the impact of the amount enrolled in CREP on water use.

Identification of the fixed effects regressions relies on the key assumption that enrolled and unenrolled units would have similar water use trends in the absence of CREP. Figure 7.1 plots the mean annual water use per acre for enrolled and unenrolled units from 1996 to 2016. The figure provides water use trends for unenrolled units in all of Kansas and of unenrolled units only in the CREP region. In the years before 2008, water use per acre of enrolled units is higher than either group of unenrolled units. As I discuss below, the differences are only partially due to CREP eligibility requirements, which exclude low water use units from enrolling. Despite differences in use per acre, there do not appear to be differing trends in water use between enrolled and unenrolled units in the pre-policy period. However, after policy initiation in 2008, water use diverges between enrolled and unenrolled units. As more acreage is enrolled, average water use continues to decrease for enrolled units.

Even if enrolled and unenrolled units have similar pre-policy water use trends, they still may differ in ways that can influence future water use. Table 7.1 provides

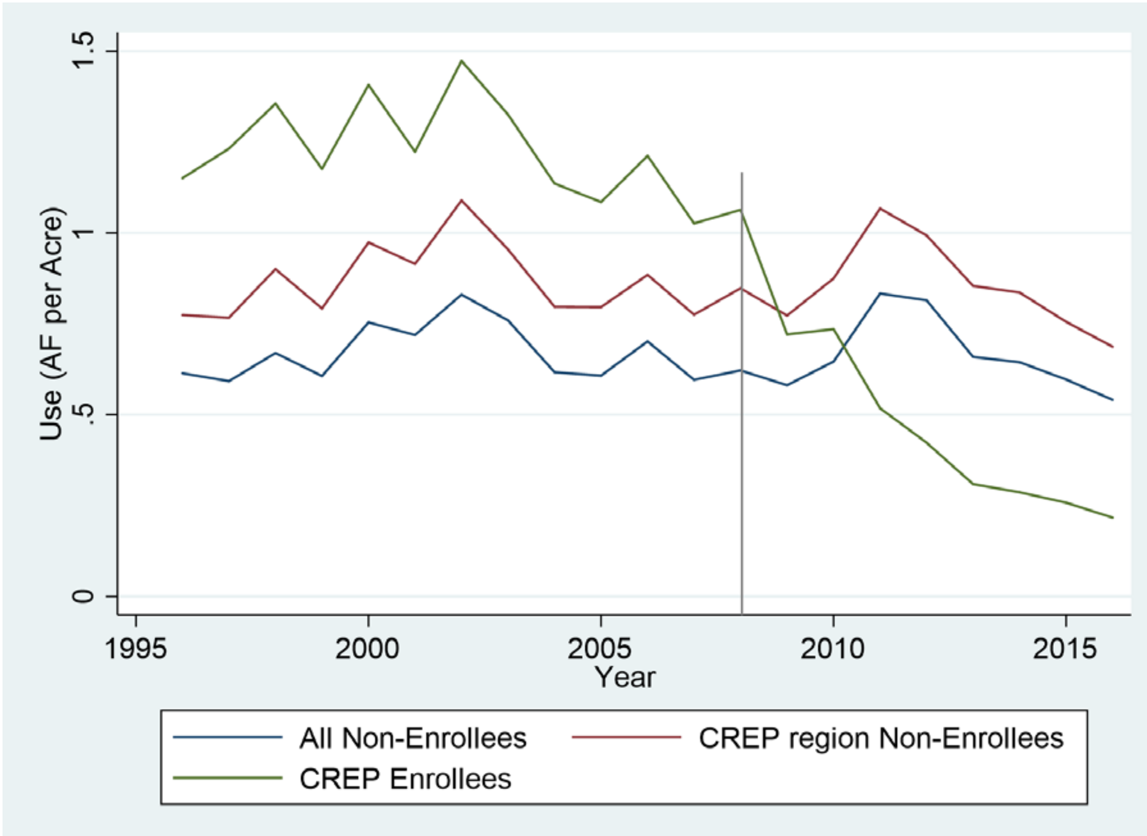

Figure 7.1: Use per acre over time for treatment and unmatched controls
Note: Water use trends between the treatment and control groups can only be directly compared in the years before 2008, when the policy began. A vertical line separates water use before and after 2008. After 2008, the average water use of the enrolled group sharply declines over time as a greater number of water rights are enrolled.

the sample means of the enrolled and unenrolled units in the entire CREP region, as well as p-values for t-tests of the differences in means. There are several significant differences in means of covariates. There are large differences between the two groups in the wind erosion index (WEI) and the non-irrigated capability class. These difference are unsurprising, as the UAR CREP explicitly uses these criteria in setting incentive rates. There are also large differences in means for characteristics that are not used to set incentives. For example, differences in the national commodity crop productivity index (NCCPI), a general index of soil productivity, are very large between the samples. Also, differences in depth to water and water unit size (net acres authorized) are highly significant. Finally, on average water use per acre for enrolled units is well above eligibility requirements and is significantly higher than the water use of unenrolled units. This implies that less valuable water rights, those that enroll in CREP, do not necessarily have lower water use.

Table 7.1: Difference in Means of All Enrolled and Unenrolled Water Units in CREP Region

	Not Enrolled	Enrolled	p-value
Wind Erosion Index	91.86	178.7	1.1e-62
National Commodity Crop Productivity Index	0.326	0.183	9.2e-34
Slope Gradient	3.169	8.506	4.6e-37
Non-Irrigated Capability Class	2.853	5.356	2.6e-45
Sat Thickness (in feet)	123.1	155.5	0.000083
Missing Sat Thickness	0.0154	0.0192	0.76
Depth to Water (in feet)	62.65	95.47	0.00014
Missing Depth	0.380	0.442	0.20
Net Acres Authorized	300.1	485.3	0.00000026
Avg Water Use per Acre (AF/Acre)	0.918	1.233	9.8e-10
Number of Water Units	2,334	104	

Because the unmatched sample has such poor covariate balance, a one-to-one match of enrolled units to unenrolled units without replacement is created based on the observables in table 7.1. Calipers are set so that for each matched pair of units, all covariate values must be within one standard deviation of each other. As shown in table 7.2, the matched control group is very similar to the treated group for all variables. All but one of the variables have insignificant differences between the enrolled and unenrolled groups. Only the difference in the wind erosion index is significant, with a p-value of 0.099. A total of 100 enrolled units are matched to unenrolled units. Four enrolled units are left unmatched and are removed from the sample. Removing these units may mean that the matched sample does not perfectly represent the treated population (Ferraro and Miranda 2017). However, four observations are unlikely to change the marginal effects much, so that any bias resulting from omission should be small.

Table 7.2: Difference in Means of Enrolled and Caliper Matched Unenrolled Units

	Not Enrolled	Enrolled	p-value
Wind Erosion Index	163.0	179.3	0.099
National Commodity Crop Productivity Index	0.193	0.182	0.31
Slope Gradient	8.538	8.525	0.99
Non-Irrigated Capability Class	5.230	5.380	0.60
Sat Thickness (in feet)	164.0	155.3	0.42
Missing Sat Thickness	0.0200	0.0200	1
Depth to Water (in feet)	91.95	95.76	0.80
Missing Depth	0.450	0.450	1
Net Acres Authorized	387.5	398.2	0.84
Avg Water Use per Acre (AF/Acre)	1.240	1.259	0.79
Number of Water Units	100	100	

Figure 7.2 provides mean values of annual water use per acre from 1996 to 2016 for enrolled units and unenrolled units from the caliper matched sample. Unenrolled units have similar levels and trends in water use per acre as the enrolled units. The unenrolled group closely matches trends in pre-2008 water use per acre for the enrolled group. Propensity score matching is also used as an alternative matching approach. Because the caliper matching technique outperforms the propensity score matching technique in both covariate balance and trends, as we will see, it is used as the main approach in estimating fixed effects water use regressions. However, the covariate balance, parallel trends, and fixed effects regressions using propensity score are provided later as a robustness check.

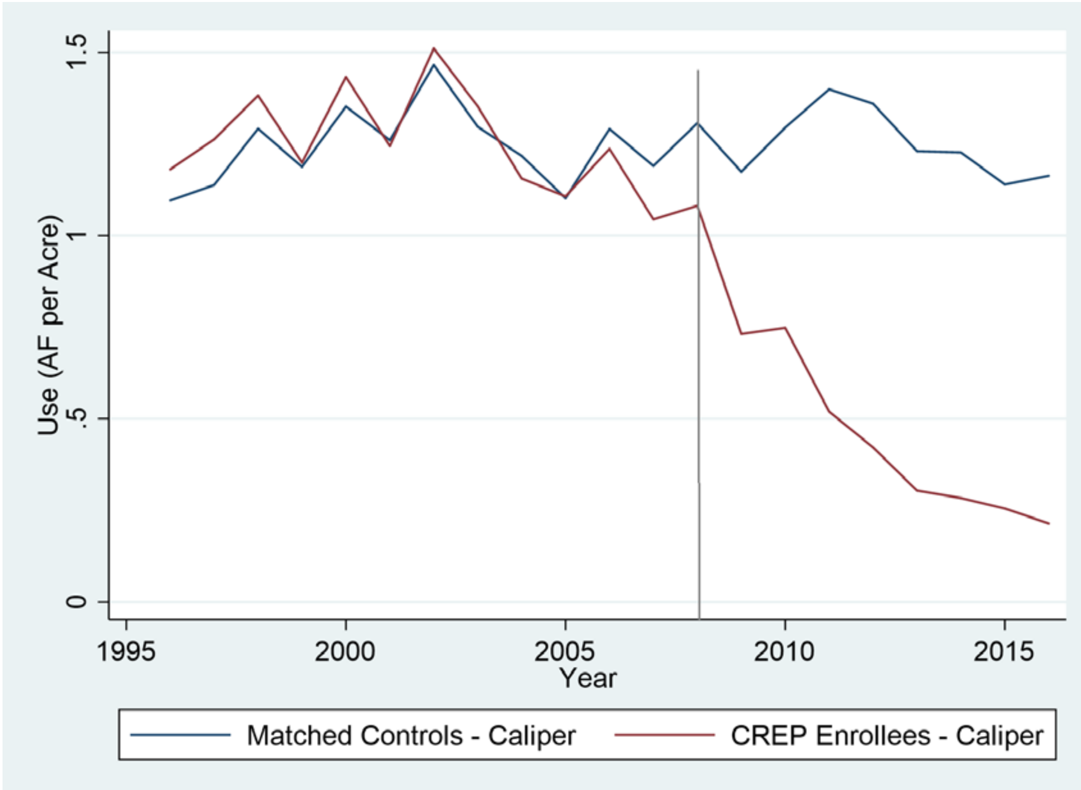

Figure 7.2: Use per acre over time for treatment and caliper matched controls
Note: Water use trends between the treatment and control groups can only be directly compared in the years before 2008, when the policy began. A vertical line separates water use before and after 2008. After 2008, the average water use of the enrolled group sharply declines over time as a greater number of water rights are enrolled.

Tables 7.3 and 7.4 provide results of fixed effects regressions estimating the effects of acre-feet per acre and proportion of authorized acres enrolled in CREP on annual water use per acre, respectively. Each regression includes 100 enrolled and 100 unenrolled units from the sample created using caliper matching, for 21 years from 1996 to 2016. The first two columns of each table provide results which correspond with equations 6.1 and 6.2. The coefficient of most interest in each regression is the effect of the amount enrolled in CREP once irrigation is required to cease completely on an enrolled plot of land. Coefficients for anticipation and enrollment measure the effects on water use in the years leading up to the point where water rights are fully retired. Standard errors are clustered by water unit for all fixed effects regressions.

Column 1 of table 7.3 provides results for a specification corresponding to equation 6.1. Each AF of authorized use that a water unit enrolls in CREP reduces annual water use by 0.776 AF, once farmers are required to cease irrigation completely. Farmers reduce water use by about half that amount in the three years directly after enrollment, when some water use is authorized to establish a conservation crop. GMD-year effects are included to control for annual influences on water use that may vary across space, such as temperature or rainfall. Column 2 provides results that correspond to equation 6.2. This regression allows for the possibility that farmers adjust water use after the program is announced. The table indicates that farmers do not increase water use to qualify for the program, and if anything, ramp down use in the immediate years before enrollment. When anticipation effects are allowed, the effect of enrollment on water use changes to 0.816 AF for every AF retired. Both columns 1 and 2 suggest that farmers would use a high proportion of their authorized water use had they not enrolled in CREP. Further, the portion is well above the eligibility requirement that specifies that farmers that enroll must use more than 50% in a set of specified prior years. This large impact implies that farmers that enroll are not simply those who use close to the eligibility requirement. As a further point of comparison, eligible unenrolled units in the CREP region used 72% of their total authorized use in the post-policy period of 2008 to 2016. This is well below the 82% savings for CREP enrollees.

Table 7.3: Effect of AF per Acre Retired in CREP on AF per Acre Water Use of Water Unit (Caliper Matched)

VARIABLES	(1) FE	(2) FE	(3) FE
Anticipation (AF/acre)		-0.159***	-0.171***
		(0.035)	(0.035)
After Enrolling (AF/acre)	-0.375***	-0.431***	-0.429***
	(0.026)	(0.031)	(0.032)
No Irrigation Allowed (AF/acre)	-0.776***	-0.816***	-0.796***
	(0.027)	(0.026)	(0.029)
GMD X Year FEs	Included	Included	Included
Late Year FEs	Not Included	Not Included	Included
Constant	1.138***	1.138***	1.138***
	(0.038)	(0.037)	(0.038)
Observations	4,200	4,200	4,200
R-squared	0.523	0.532	0.540
Number of Water Units	200	200	200

*** p<0.01, ** p<0.05, * p<0.1
Note: Standard errors clustered by water unit are in parentheses

Table 7.4 provides results for the water savings effect of the proportion of a water unit's authorized acreage retired in CREP. The results are similar to those in table 7.3, but the coefficients are larger. In the regression without anticipation effects, an acre retired results in an average of 1.446 AF of reduced water use. The effect increases slightly to 1.522 AF when anticipation effects are included, reflecting the same ramp down effect of the policy. The effect for retired acreage is almost twice the effect of retired acre-feet authorized, which is due to the nearly two to one ratio of acre-feet retired versus acreage retired (see table 4.1). The effects in table 7.4 can be compared to the other CREP eligibility requirement that farmers must apply more than 0.5 AF per acre on enrolled land in a set of specified years prior to enrolling. The results suggest that farmers would have used about three times that amount on the land that they retired. This confirms the above result that enrollments in CREP lead to water savings far above what one would expect based on eligibility requirements.

Table 7.4: Effect of Proportion of Acreage Retired in CREP on AF per Acre Water Use of Water Unit (Caliper Matched)

VARIABLES	(1) FE	(2) FE	(3) FE
Anticipation (% of total acreage)		-0.292***	-0.321***
		(0.062)	(0.062)
After Enrolling (% of total acreage)	-0.688***	-0.794***	-0.790***
	(0.049)	(0.057)	(0.059)
No Irrigation Allowed (% of total acreage)	-1.446***	-1.522***	-1.477***
	(0.054)	(0.053)	(0.057)
GMD X Year FEs	Included	Included	Included
Late Year FEs	Not Included	Not Included	Included
Constant	1.138***	1.138***	1.138***
	(0.038)	(0.038)	(0.038)
Observations	4,200	4,200	4,200
R-squared	0.516	0.525	0.534
Number of Water Units	200	200	200

*** p<0.01, ** p<0.05, * p<0.1
Note: Standard errors clustered by water unit are in parentheses

Next, we examine whether accounting for dynamic selection bias changes the results. Figure 7.3 shows water use trends over time for early and late enrolled units and their caliper matched unenrolled units. Prior to program initiation, late enrollments and their matches use less water per acre than early enrollments. However, trends still appear to be parallel. Regressions are conducted that account for the possibility that units that enroll late in the program differ from early enrollees. These regressions include GMD X Year time dummies for late enrolled units and their matches, corresponding with equation 6.3. Results are provided in the third columns of tables 7.3 and 7.4. The coefficients from these regressions do not differ much from those in column 2 of the same tables, suggesting that dynamic selection bias is a minor concern. In general all of the regressions in tables 7.3 and 7.4 suggest that CREP results in a large amount of water savings for those that enroll.

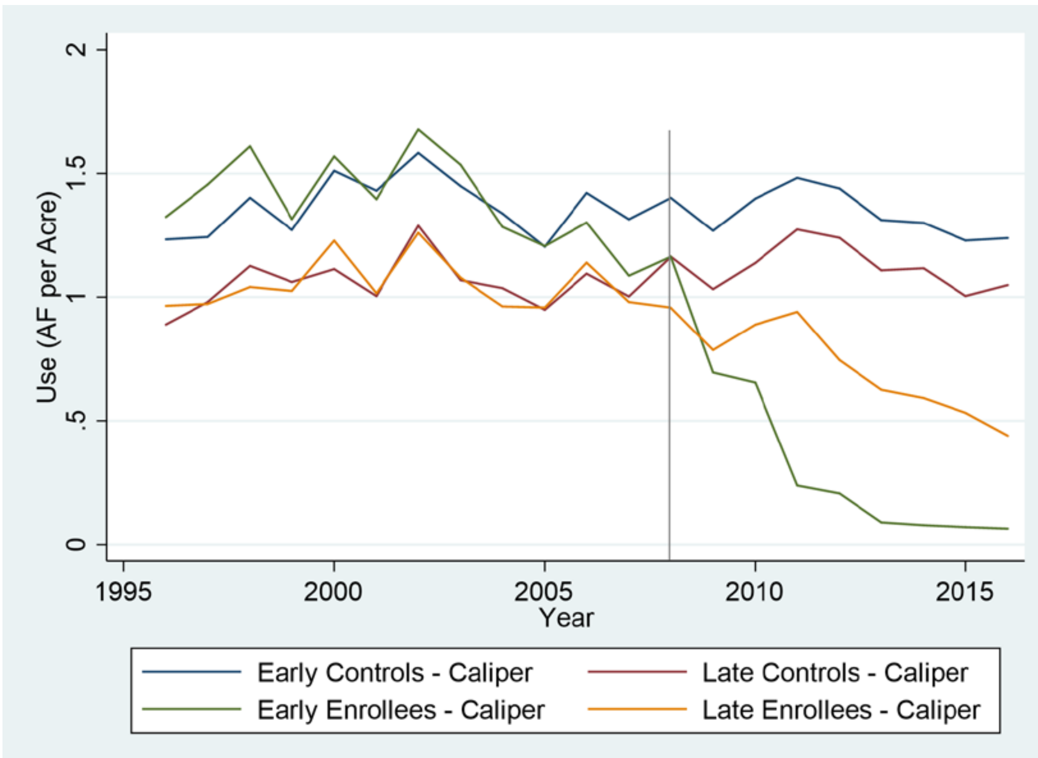

Figure 7.3: Use per acre over time for treatment and caliper matched controls, late and early enrollments

Note: Water use trends between the treatment and control groups can only be directly compared in the years before 2008, when the policy began. A vertical line separates water use before and after 2008. After 2008, the average water use of the enrolled group sharply declines over time as a greater number of water rights are enrolled.

We now conduct water use regressions using propensity score matching to show that the results do not depend on the matching approach used. First, a probit regression is run to predict the probability of being an enrolled unit in the CREP region, where the independent variables are the same as in tables 7.1 and 7.2. Results of the probit regression are shown in table 7.5. Many of the same variables that explain differences between enrolled and unenrolled units also predict CREP enrollment. Predicted probabilities of enrollment are generated from the regression and used to match each enrolled unit to an unenrolled unit. A one-to-one matching routine without replacement is used, where each enrolled unit is matched with the unenrolled unit from inside or outside the CREP region with the closest propensity score. Covariate balance of the propensity score match is tested in table 7.6. The enrolled and unenrolled units have much closer observables than in the unmatched sample. However, the caliper matching approach results in better covariate balance than the propensity score matching approach. The main advantage of this approach is that it matches all 104 treatment units. Figure 7.4 shows annual water use trends from 1996 to 2016 for enrolled units and unenrolled units from the propensity score matched sample. Unenrolled units have similar levels and trends in water use per acre as the enrolled units. However, levels do not match as closely as with the caliper matched sample.

Columns 1 and 2 of tables 7.7 and 7.8 provide results from fixed effects regression of annual water use per acre for water units matched using propensity scores, corresponding with equations 6.1 and 6.2. Coefficients from these regressions are similar to those using caliper matching. By and large, these results do not differ much from those from the caliper matched sample. I also estimate fixed effects regressions with propensity score matching using the specification in equation 6.3. Figure 7.5 provides water use trends for early and late enrollees and their matched unenrolled units using propensity scores. Trends match closely between and across both groups of enrolled and unenrolled units. However, water use from the caliper matched sample matches more closely. Despite this slight discrepancy, columns 2 and 3 of tables 7.7 and 7.8 yield similar results, again suggesting that dynamic selection is also a minor concern for the propensity score matched sample.

Table 7.5: Water Unit Propensity to Enroll Some Acres

VARIABLES	(1) Probit	(2) SE
Wind Erosion Index	0.0189***	(0.00283)
National Commodity Crop Productivity Index	-4.117***	(1.385)
Slope Gradient	-0.244***	(0.0359)
Non-Irrigated Capability Class = 2 [a]	-0.117	(0.315)
Non-Irrigated Capability Class = 3 [a]	0.0566	(0.263)
Non-Irrigated Capability Class = 4 [a]	0.332	(0.272)
Non-Irrigated Capability Class = 6 [a]	0.987***	(0.284)
Non-Irrigated Capability Class = 7 [a]	1.207***	(0.356)
Sat Thickness	-0.00370***	(0.000982)
Missing Sat Thickness	-0.782*	(0.428)
Depth to Water (in feet)	0.00205**	(0.000826)
Missing Depth	0.432**	(0.172)
Net Acres Authorized	0.000359***	(0.000108)
Avg Water Use per Acre (AF/Acre)	0.0762	(0.121)
Constant	-2.224***	(0.599)
Number of Water Units	16,308	

*** p<0.01, ** p<0.05, * p<0.1
Standard errors in parentheses
[a] Default category is NICC = 0. No enrollees had levels 1 and 5, so these categories were not included in the regression.

Table 7.6: Difference in Means of Enrolled and Propensity Matched Unenrolled Units

	Not Enrolled	Enrolled	p-value
Wind Erosion Index	166.6	178.7	0.22
National Commodity Crop Productivity Index	0.226	0.183	0.00020
Slope Gradient	6.200	8.506	0.00093
Non-Irrigated Capability Class	4.731	5.356	0.024
Sat Thickness	128.7	155.5	0.0096
Missing Sat Thickness	0.0192	0.0192	1
Depth to Water (in feet)	83.03	95.47	0.64
Missing Depth	0.471	0.442	0.68
Net Acres Authorized	387.2	485.3	0.21
Avg Water Use per Acre (AF/Acre)	0.974	1.233	0.00078
Number of Water Units	104	104	

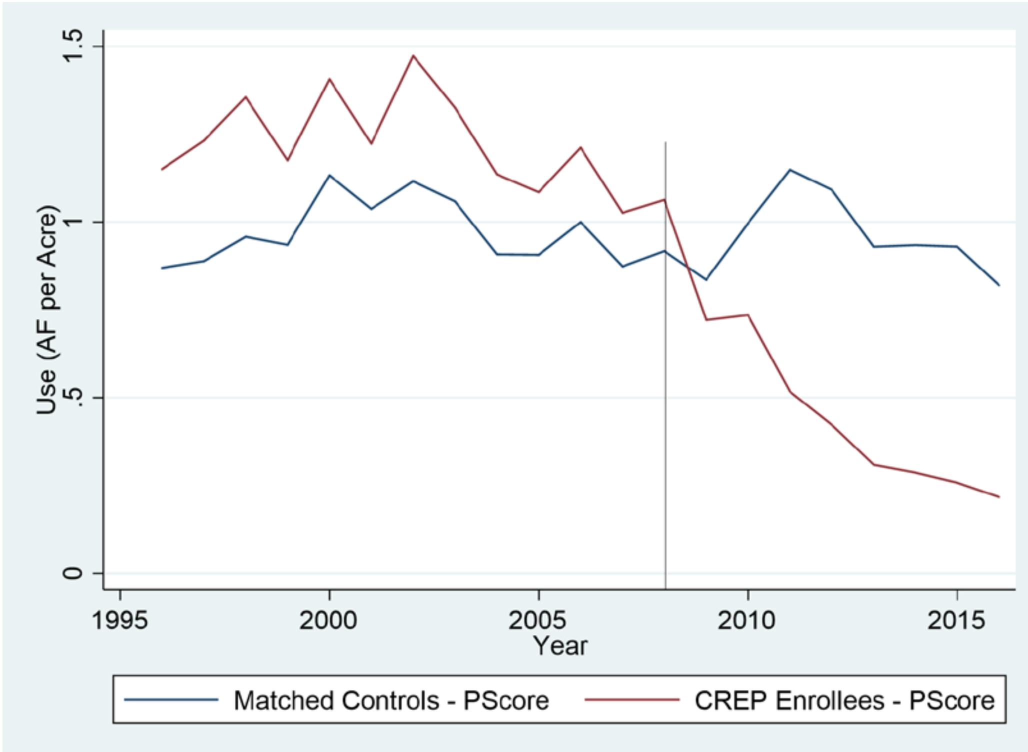

Figure 7.4: Use per acre over time for treatment and propensity score matched controls

Note: Water use trends between the treatment and control groups can only be directly compared in the years before 2008, when the policy began. A vertical line separates water use before and after 2008. After 2008, the average water use of the enrolled group sharply declines over time as a greater number of water rights are enrolled.

Table 7.7: Effect of AF per Acre Retired in CREP on AF per Acre Water Use of Water Unit (Propensity Matched)

VARIABLES	(1) FE	(2) FE	(3) FE
Anticipation (AF/acre)		-0.130***	-0.139***
		(0.036)	(0.036)
After Enrolling (AF/acre)	-0.348***	-0.401***	-0.386***
	(0.026)	(0.032)	(0.034)
No Irrigation Allowed (AF/acre)	-0.754***	-0.792***	-0.776***
	(0.027)	(0.026)	(0.028)
GMD X Year FEs	Included	Included	Included
Late Year FEs	Not Included	Not Included	Included
Constant	1.010***	1.010***	1.010***
	(0.033)	(0.033)	(0.033)
Observations	4,368	4,368	4,368
R-squared	0.547	0.552	0.563
Number of water units	208	208	208

*** p<0.01, ** p<0.05, * p<0.1

Note: Standard errors clustered by water unit are in parentheses

Table 7.8: Effect of Proportion of Acreage Retired in CREP on AF per Acre Water Use of Water Unit (Propensity Matched)

VARIABLES	(1) FE	(2) FE	(3) FE
Anticipation (% of total acreage)		-0.233***	-0.256***
		(0.063)	(0.064)
After Enrolling (% of total acreage)	-0.637***	-0.735***	-0.706***
	(0.049)	(0.059)	(0.062)
No Irrigation Allowed (% of total acreage)	-1.402***	-1.474***	-1.432***
	(0.054)	(0.053)	(0.058)
GMD X Year FEs	Included	Included	Included
Late Year FEs	Not Included	Not Included	Included
Constant	1.010***	1.010***	1.010***
	(0.033)	(0.033)	(0.033)
Observations	4,368	4,368	4,368
R-squared	0.540	0.545	0.557
Number of water units	208	208	208

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: Standard errors clustered by water unit are in parentheses

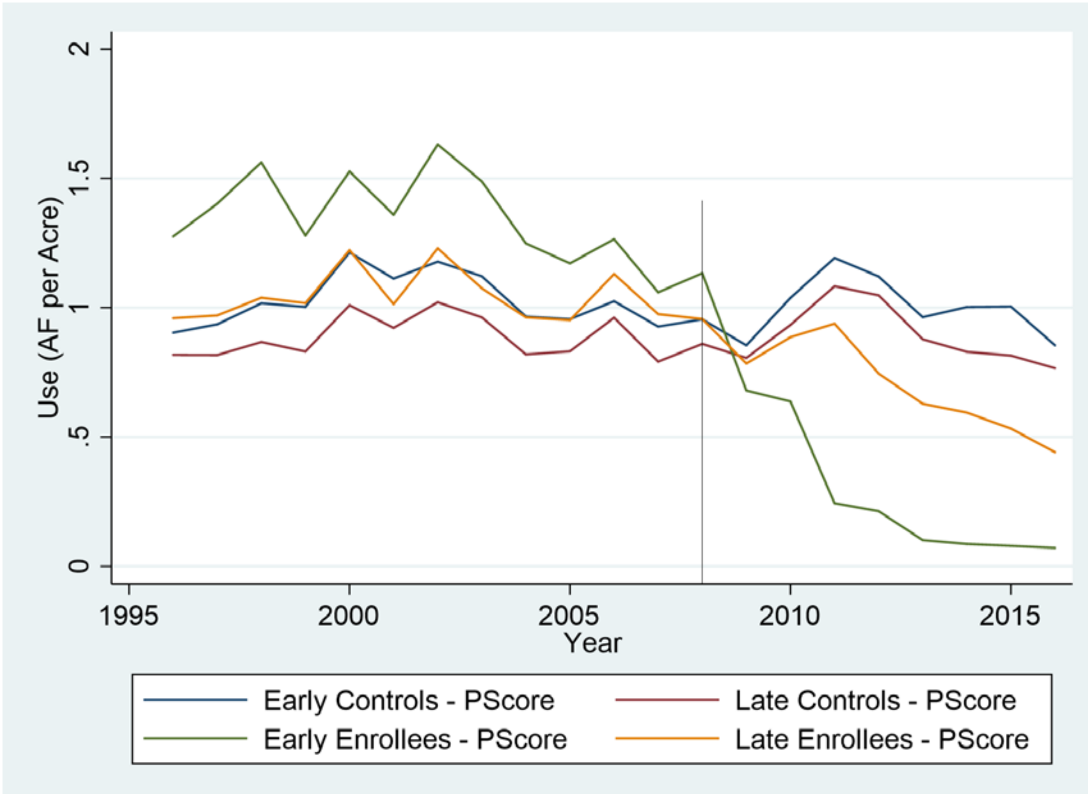

Figure 7.5: Use per acre over time for treatment and propensity score matched controls, late and early enrollments

Note: Water use trends between the treatment and control groups can only be directly compared in the years before 2008, when the policy began. A vertical line separates water use before and after 2008. After 2008, the average water use of the enrolled group sharply declines over time as a greater number of water rights are enrolled.

7.2. Probability of Enrollment and Simulation

The following section provides results for the cost-effectiveness analysis of incentive-based water rights retirement programs. First, enrollment decisions in the CREP policy region are modeled to determine which factors influence the probability of enrollment. Results for random effects probit and logit models as specified in equation 6.8 are provided in table 7.9. Columns 1 and 2 provide coefficients for probit and logit models of enrollment, respectively. To calculate the net present value (NPV) of incentive rates, first the NPV of annual FSA rental payments is calculated assuming a 3% interest rate for 15 years of payments. Net present values for rental payments are then added to one-time payments from Kansas to get total CREP payments, which are then converted to 2018 dollars using the GDP deflator. In both columns 1 and 2, increases in NPV of CREP payments have a significant positive impact on enrollment. This effect reflects the pattern seen in table 4.1, where most enrollments occur immediately or soon after rate increases. Importantly, there is significant unobserved heterogeneity in each regression. The statistic called rho is a function of the estimated standard deviation of the random effects in each regression. Likelihood ratio tests determine whether the hypothesis that rho equals zero can be rejected. In both cases, the chi-squared statistics for these tests are very high, suggesting that unobserved heterogeneity plays an important role in modeling enrollment. Conventional standard errors are used for each enrollment regression.

The effects of most other covariates on enrollment are similar between the two models. A higher wind erosion index significantly increases the probability of enrollment, even after accounting for higher incentive rates paid to highly erodible plots. This implies that WEI influences the value of water rights even after accounting for regional differences in irrigated land values. A few other factors have significant coefficients with the expected signs. Having a higher soil productivity, as measured by a higher national commodity crop productivity index, leads to a significantly smaller probability of enrolling in CREP. A lower saturated thickness increases the probability of enrollment. A higher depth to water also increases the probability of enrollment, but the effect is only statistically significant in the logit model. Surprisingly, having a higher slope gradient decreases the probability of enrolling in CREP. GMD fixed effects are intended to measure time invariant heterogeneity across space. The default category is no GMD, meaning that a water right is located in a region not under the jurisdiction of a GMD. The GMD fixed effects are large but only significant in one case, suggesting that there may be regional differences in the value of water rights that are not reflected in differences in incentive rates. Finally, water use has a surprising impact on the probability of enrollment in CREP. In the probit model, water use has no significant impact on enrollment and in the logit model it positively predicts enrollment. This result provides a partial explanation for the high water use savings attributable to CREP found in the last section.

Using results from the estimated probit model from table 7.9, policy simulations of enrollment decisions are run to evaluate the cost-effectiveness of alternative incentive-based retirement policies. Table 7.10 provides sample statistics evaluating the six main policy scenarios and includes a measure of the absolute cost-effectiveness with which to compare policies. Absolute cost-effectiveness for a given policy is calculated as the ratio of the average cost per unit saved for that policy and

Table 7.9: Binary Choice Regressions of CREP Enrollment

VARIABLES	(1) Random Effects Probit	(2) Random Effects Logit
NPV of CREP payments	0.00209***	0.00279***
	(0.000407)	(0.000621)
Wind Erosion Index	0.0531***	0.0636***
	(0.00967)	(0.0105)
Available Water Storage	0.00199	-0.000430
	(0.00777)	(0.0103)
National Commodity Crop Productivity Index	-10.42**	-13.32**
	(4.542)	(5.708)
Slope Gradient	-0.510***	-0.616***
	(0.110)	(0.110)
Saturated Thickness (ft)	-0.0113***	-0.0148***
	(0.00309)	(0.00404)
Missing Sat Thickness	-0.586	-0.549
	(2.449)	(3.689)
NICC Level 3-5 [a]	-0.757	-1.047
	(0.607)	(0.685)
NICC Level 6-7 [a]	0.283	0.249
	(0.862)	(1.016)
Missing NICC	-1.668**	-2.093**
	(0.792)	(0.945)
Corn Grower	-1.125	-1.721
	(1.009)	(1.412)
Alfalfa Grower	0.986	1.636
	(0.790)	(1.034)
Wheat Grower	-0.289	-0.292
	(1.274)	(1.764)
Missing Crop Data	2.984*	3.815
	(1.688)	(2.479)
Center Pivot [b]	1.500	1.982
	(1.413)	(1.757)
Center Pivot – LEPA[b]	0.931	1.231
	(1.247)	(1.654)
Missing Irrigation System	0.190	0.369
	(1.902)	(2.756)
Depth to Water	0.00564	0.00936**
	(0.00365)	(0.00429)
Missing Depth	1.149	1.731*
	(0.731)	(0.890)
Avg Water Use per Acre	0.952	1.225*
	(0.606)	(0.704)
GMD 3 [c]	-0.762	-0.956
	(2.684)	(3.666)
GMD 5 [c]	-4.628	-6.993*
	(2.901)	(4.143)
Constant	-13.77***	-18.85***
	(3.546)	(5.158)
Observations	23,696	23,696
Number of Water Units	2,441	2,441
rho [d]	0.923	0.880
X2 of LR test	101.6	97.31

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
[a] Default category is NICC Level 0-2
[b] Default category is flood irrigation system
[c] Default category is no GMD
[d] The LR test rejects the hypothesis that rho = 0

the perfect targeting policy at the average level of water savings obtained from the imperfect policy. A policy with an absolute cost-effectiveness of 1 pays all farmers who enroll their exact opportunity cost. Table 7.10 suggests that the policy that pays different rates to different farmers and that increases rates over time performs the best. On average, the program is 1.53 times the cost of the optimal policy. The rollout policy that pays a uniform rate per AF of prior water use performs nearly as well. The synthetic CREP policy has an absolute cost-effectiveness of 1.8 times the cost of the optimal policy. These results suggest that per AF incentives could improve the cost-effectiveness of CREP substantially.

Table 7.10: Cost-Effectiveness of Simulated Policies

Simulated Policies	Total # Enrolled (Mean)	Total AF Water Saved (Mean)	Cost ($) per AF Water Saved (Mean)	Cost per Unit Water Saved - Optimal Policy ($/AF)	Absolute Cost-Effectiveness
Per Acre (constant)	54.46 (6.06)	15,964.04 (2,417.59)	1,631.54 (116.87)	856	1.91
Per Acre (rollout)	61.24 (6.69)	18,039.33 (2,544.91)	1,626.11 (118.23)	904	1.80
Per AF (constant)	51.45 (6.43)	17,050.93 (2,491.15)	1,465.18 (57.61)	882	1.66
Per AF (rollout)	58.72 (6.55)	19,682.08 (2,688.43)	1,454.67 (68.66)	939	1.55
Targeted (constant)	48.92 (6.55)	16,162.07 (2,750.18)	1,420.02 (58.44)	861	1.65
Targeted (rollout)	54.11 (7.35)	18,183.61 (2,922.23)	1,392.25 (72.47)	907	1.53
Real CREP	122.00	30,170.59	1,144.44		

Note: Standard deviations from simulation of 100 runs are in parentheses. Values for optimal policy are derived by taking the integral of the estimated inverse water savings supply curve up to the mean savings for that policy. Because cost per unit saved are increasing in savings, policies with higher expected water savings have higher costs for the optimal policy. The values for “Real CREP” are calculated using actual enrollments and incentive rates in the UAR CREP region. All simulated programs are conducted entirely outside the UAR CREP region.

The absolute cost-effectiveness is determined using the three simulations described before. First, policy simulations of enrollments are conducted to set the incentive rates that maximize expected water savings for six incentive-based policies, given a budget constraint of $25 million (simulation 1). Each simulation uses pre-2008 average water use as a proxy for future water savings. A second simulation is then run to determine the cost per unit saved of each incentive scheme (simulation 2). The second simulation sets incentive rates using pre-2008 farmer water use and results from the first simulation. It calculates the water savings of each policy using post-2008 average water use. As table 7.10 shows, the per acre incentive policy that remains constant over the entire period leads to an average total savings of 15,964 AF, at an average cost of $1,632 per AF saved. Next, a per acre rollout policy, the synthetic CREP policy, has an expected savings of 18,040 AF, at a cost of $1,626 per AF saved. Next are policies that set incentives based on pre-2008 water use. The constant and rollout per AF policies have substantially lower costs per AF saved, at $1465 and $1455 per AF saved, respectively. Finally, the costs per AF saved of each of these policies (constant and rollout) are even lower than the per AF policies.

Next the absolute cost-effectiveness is calculated for each policy using the cost per unit saved of the optimal policy for a given level of water savings. For example, the per acre policy results in a water savings of 15,964 AF. Taking the integral under the supply curve of water savings from simulation 3 (figure 7.6), the total cost of the perfect foresight policy for a savings of 15,964 AF is about $13.7 million. Thus the optimal policy has a cost of $856 per AF saved at that level of water savings. Thus the absolute cost-effectiveness of the synthetic CREP policy is

$1,632/$856=1.91. The last row of table 7.10 provides results for the real CREP policy. In lieu of actual post-2008 water use, the savings from the real CREP policy are calculated using the coefficient of water savings once irrigation ceases entirely given in table 7.4. Table 7.10 suggests that the cost per AF saved of the real CREP policy is $1,144 per AF. This value should not be used to compare the cost-effectiveness of CREP with simulated policies, as the estimates come from different samples of different sizes. However, the low value suggests that the designers of CREP chose a policy region with a large amount of marginal land and thus more plots likely to enroll at lower incentive rates. Further, it suggests that applying a similar policy to another region is likely to be more expensive for a given amount of water savings.

Table 7.11 provides results from simulation 3 for a range of incentive rates. The values in the first column represent the incentive rates paid for each AF of average post-2008 water use. Using data from 100 simulation runs at each incentive rate, table 7.11 also provides means and standard deviations of total rights enrolled, total AF of water use saved, and the cost per AF of water saved. Because incentive rates in the first simulation are based on actual future water savings, the mean value of costs per AF saved are identical to incentive rates. As seen in the table, as incentive rates increase, the number of rights enrolled and amount of water savings both increase. This relationship is a direct result of the positive coefficient for incentives in the estimated probit model. The data from these simulations are then used to estimate an inverse supply curve as specified in equation 6.12. The results of the regression are shown in table 7.12 and the resulting fitted inverse supply curve is depicted in figure

7.6. As water savings increase, the required incentive rate increases at a decreasing rate. This curve is used to assess the total cost of a perfect targeting policy. The total cost is calculated by taking the integral under the inverse supply curve for a given level of water savings. Figure 7.6 also depicts a step function to show how payments made in the simulations compare to the estimated supply curve. If the estimated supply curve depicted in the figure represents the true supply curve, farmers with a given value for their water rights will be overpaid by the amount represented by the vertical distance from the step function to the supply curve.

The results of the policy simulations suggest two main findings. First, policies that set incentives based on prior water use outperform policies that pay rates based on acreage retired. The per AF policies have absolute cost-effectiveness ratings ranging from 1.53 to 1.66 times the costs of the optimal policy, compared to a range of 1.8 to 1.91 for per acre policies. Second, policies that increase rates over time perform better than policies that keep the rates offered constant over time. This result is due to the ability of rollout policies to capture unobserved differences in farmers' willingness to accept to retire their water rights. The UAR CREP has been using this approach. Although CREP has shown a high level of water savings for those that have enrolled, policy makers that would like to more efficiently reduce water savings may consider incentives based on prior water use. However, it should be noted that water savings is not the only goal of the UAR CREP.

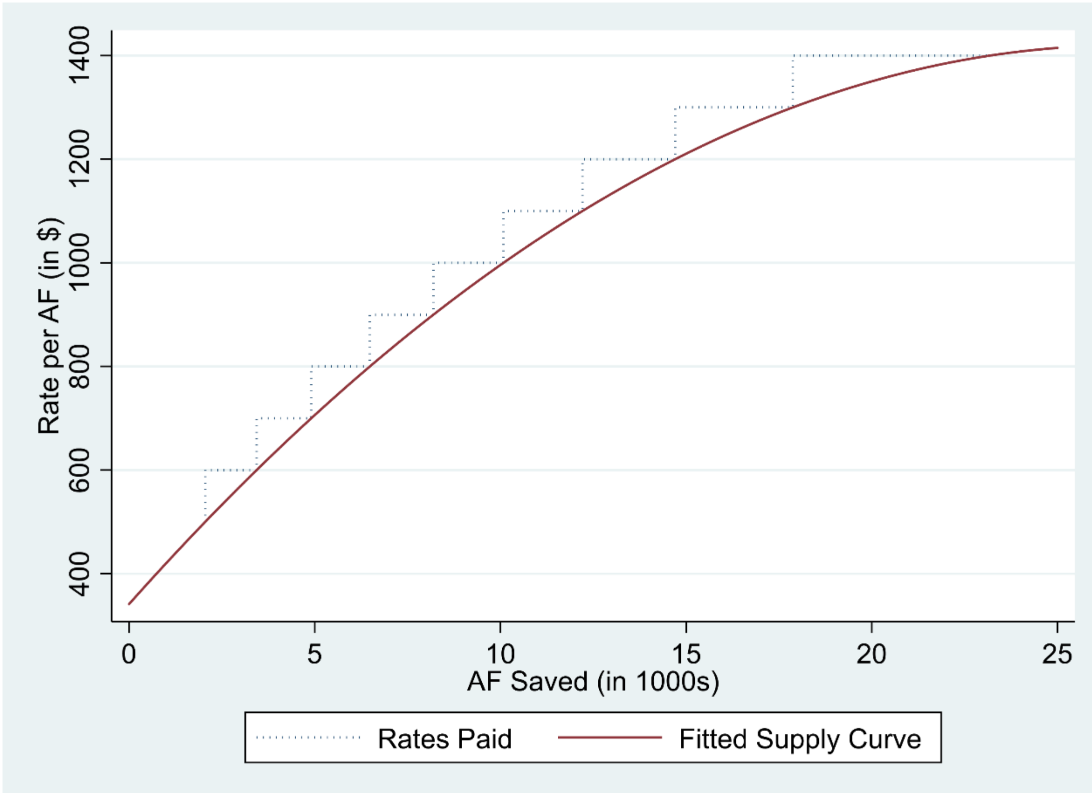

Figure 7.6: Water savings supply curve for all rights

Table 7.11: Sample Statistics of Perfect Foresight Policy Simulations

Incentives ($ per post-2008 AF use)	Total # Enrolled (Mean)	Total # Enrolled (SD)	Total AF Water Saved (Mean)	Total AF Water Saved (SD)	Cost ($) per AF Water Saved (Mean)	Cost ($) per AF Water Saved (SD)	Cost ($) per Enrollee (Mean)	Cost ($) per Enrollee (SD)
500	12.51	4.12	3,932.63	1,832.88	500.00	0.00	154,610.80	45,987.53
600	14.77	4.53	4,731.29	1,950.26	600.00	0.00	190,681.41	47,288.86
700	17.46	4.89	5,724.66	2,078.90	700.00	0.00	228,194.91	49,512.23
800	20.49	5.15	6,818.61	2,216.86	800.00	0.00	265,282.75	52,791.81
900	24.11	5.11	8,094.91	2,303.12	900.00	0.00	301,216.38	52,420.48
1000	28.87	5.74	9,818.99	2,496.02	1,000.00	0.00	339,792.09	50,479.60
1100	34.02	6.51	11,649.49	2,867.00	1,100.00	0.00	375,584.22	49,026.77
1200	39.99	7.08	13,823.32	3,164.72	1,200.00	0.00	414,094.44	50,276.38
1300	46.71	7.94	16,207.32	3,490.53	1,300.00	0.00	450,587.53	51,589.88
1400	55.21	8.39	19,448.07	3,801.83	1,400.00	0.00	492,890.31	55,881.43

Table 7.12: Regression of Cost per AF Saved on Total Water Savings

VARIABLES	(1) OLS	(2) SE
Total Use Saved (in 1000 AF)	80.48***	(2.696)
Total Use Saved Squared	-1.501***	(0.107)
Constant	341.2***	(14.71)
Observations	1,000	
R-squared	0.782	

*** p<0.01, ** p<0.05, * p<0.1
Standard errors in parentheses

7.3. Policy Discussion

The following section discusses the relevance of the above results for larger scale policies. First, I discuss the role of spatial externalities in the effectiveness of water rights retirement programs. Second, I discuss the potential issue of anticipation effects in the context of the increasing rates mechanism discussed in the analysis. Finally, I discuss how the policy instruments analyzed above relate to other mechanisms discussed in the literature.

Because aquifers are shared resources, one might be concerned that if CREP impacts depletion rates in the aquifer, this could have some second order effects on nearby farmers' water use. One concern is that if such externalities exist, they could affect the value of the estimates in this paper of the impact of CREP on water use. Specifically, if enrollments in CREP decrease depletion for control farmers included in the fixed effects regression, this could impact their water use and thus the estimated coefficient. Because the current program is small and very few control farms in the regression are close to CREP enrollees, the effect on the regression coefficient will be negligible.

However, even if this coefficient is estimated correctly, externalities could have more general implications for the effectiveness of water rights retirement programs. If some water rights are removed from the pool of water appropriations, reduced depletion rates for nearby farmers could impact their perception of the relative impact of their own water use on depletion. These farmers may be more inclined to conserve water over time, considering the opportunity costs of future uses of the aquifer. Many studies estimate the degree to which such externalities may impact groundwater use. For example, Pfeiffer and Lin (2012) find that the average farmer in Western Kansas would decrease his water use by 2.5% annually if all surrounding farmers were to suddenly stop irrigating. However, estimates of the water use impacts and welfare benefits from groundwater management vary greatly in the literature (Koundouri 2004).

Alternatively, reduced depletion due to a rights retirement program may increase surrounding farmers' water use, due to decreases in their total energy costs. Pfeiffer and Lin (2014b) find that the elasticity of farmer water use to energy prices in Kansas is -0.26. Further, Pfeiffer and Lin (2012) find that depletion of a particular well would decrease by about 0.3% of the mean depth to groundwater per year if all surrounding farmers within a mile stopped using water, increasing energy costs by this much each year. Combining these values together, if all farmers enrolled in CREP, after ten years of the program the decreased energy costs due to cumulative reduced depletion would still only increase farmer water use by less than 1%.

A second concern about the policy implications of this analysis has to do with the anticipation effects discussed earlier related to the increasing incentive rates mechanism. In chapter 6, I argue that anticipation effects will be minimal for a small program such as CREP. However, for a bigger program, anticipation effects may be a more serious issue. In particular, anticipation effects may occur if potential participants are confident in their ability to enroll in a later period when rates are increased. Of those farmers who would profit from enrolling today, those most likely to delay their decisions will be those with the highest WTA to retire their water rights.

This is because the relative gain from a delay in enrollment is much higher when the gain from enrolling today is minimal.

Figure 7.7 below shows how anticipation effects might impact the cost effectiveness of a rate increase mechanism. Suppose a program pays incentives based on past water use and plans to increase offered incentive rates twice over a certain time span until a savings goal or budget cap is reached.[8] If the program lasts the entire time span, the rates will be increased from P_1 to P_2 to P_3 over time. If the program manager is able to set incentive rates based on expected savings as above, he could presumably set the price at P_3 from the beginning and obtain his savings goal. In this case, he would be overpaying for these savings by the area below the solid line at P_1 and above the supply curve. However, if he increases offered incentive rates over time, the program could be more cost effective. If there were no anticipation effects, as assumed in the analysis above, he would only overpay by the amount below the solid step function and above the supply curve. However, if there were anticipation effects, more farmers would receive a higher rate, and the manager would overpay by the area below the dashed step function. As the program goal or budget cap becomes closer to being met and the risk of the program ending increases, farmers are less likely to delay their decisions. Thus, the set of farmers who delay will be larger in the first round. As depicted in the figure, farmers delay for at most one period. However, as incentives drive more farmers to delay, the dashed lines will move to the left. In the extreme case, all farmers will delay two periods, and a program with increasing rates will cost the same amount as a policy that offers

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[8] I assume here that past water use is a good proxy for future water use.

P_3 from the beginning. Thus, unless there are severe anticipation effects for a program, a program rollout strategy is likely to bring cost savings over a fixed price. Further, cost effectiveness of programs can be improved by ensuring that there is a risk that farmers will lose their chance to enroll by delaying their enrollment decisions.

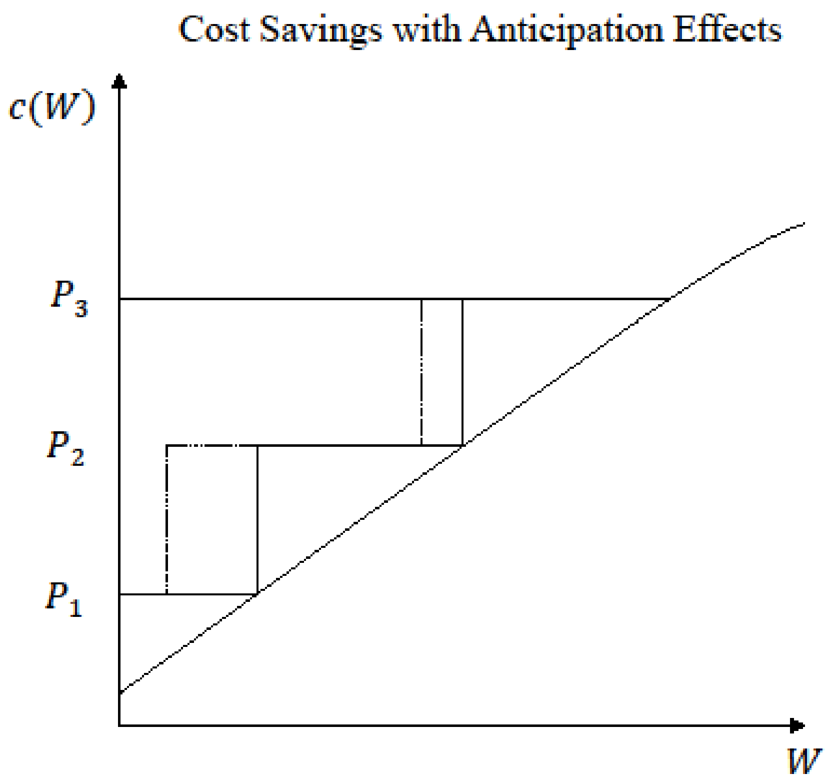


Figure 7.7: Cost savings from increasing rates, with and without anticipation effects

Finally, we consider how the mechanisms analyzed in this paper compare to other mechanisms in the literature. In particular, one feature of the current CREP, increasing incentive rates over time, can help to capture unobserved differences in values of water rights. One might suggest that auctions could be more cost effective than the mechanisms discussed in this analysis. However, the mechanisms discussed in this paper are actually more similar to common auction designs than they might appear. For example, uniform priced auctions pay a fixed price set at the maximum bid of all bidders below a certain bid cap, given some budget constraint or benefits goal. Uniform priced auctions are particularly useful for setting an appropriate price when the distribution of prices is unknown (Latacz-Lohmann and Schilizzi 2005). However, if incentive rates can be set based on supply curves based on empirical enrollment data as they are in this paper, then this is unnecessary. If such data is available, either a uniform priced auction or a constant rate policy could enroll similar sets of individuals at a similar total cost. Discriminant auctions, which pay bidders their exact bids, have more potential to improve cost effectiveness (Latacz-Lohmann and Schilizzi 2005). Discriminant auctions and the increasing rate policy discussed in this paper both aim to limit information rents by tracing out the true supply curve. In discriminant auctions, if bidders are fairly certain of how much the maximum rate they can bid is, they will general shade their bids (Latacz-Lohmann and Van der Hamsvoort 1997). This is fairly similar to the problem of anticipation effects with the rate increase policy. If farmers are fully aware of the maximum time they can wait for a rollout policy, one may similarly expect anticipation effects. Thus, bid shading and anticipation effects are situations that are likely to be impacted by similar factors.

Still, there may be some important tradeoffs between auctions and the increasing rate mechanism discussed in this paper. Particularly for large programs, increasing rates over time may be an inefficient approach, requiring that the program be implemented over a long time. This may be a problem in that it requires further costs of implementation and the benefits will be discounted. On the other hand, auctions place a higher cost of participation on sellers than fixed price mechanisms. People may also take a bit of time to make their enrollment decisions, and decisions may be influenced by factors that change from year to year. Auctions that require that people make bids immediately may further deter participation. Further, auctions can also be perceived as less transparent and fair to potential sellers (Lundberg 2018). If for these reasons auctions deter participation of low cost farmers from enrolling, this could increase the costs of savings relative to fixed prices mechanisms. Such impacts on participation can be large. For example, DePiper (2015) finds that for fishing license buybacks for crab fishermen in Maryland, fewer than half of sellers who sold their licenses under a fixed price mechanism would have participated in an auction. Thus the rollout mechanism discussed in this paper may provide a more feasible approach to improving the cost-effectiveness of conservation programs. For a small program like the current UAR CREP that focuses mostly on enrolling low quality land, the issues with auctions may outweigh the issues with an increasing rate mechanism. However, for a bigger scale program targeting higher quality land, program implementation time could be a more serious concern. Further research may be needed to understand these tradeoffs in more detail.

Chapter 8: Conclusions

This study examines the extent to which an existing water rights retirement program impacts farmer water use and determines what kinds of incentive rates are most cost-effective at saving water. Using fixed effects models with matched samples, it finds that CREP saves a high amount of water use relative to the total amount of authorized use it retires. The program effectively attracts high water use individuals, and at least in the near term, does not attract individuals with lower future water use. Further, the study evaluates cost-effectiveness of various water rights retirement incentive schemes and finds that a policy design similar to the UAR CREP, applied to an outside region, has a cost per AF saved of 1.8 times that of a perfect targeting policy. Policies that pay incentives based on prior water use and that increase rates over time are more cost effective, with costs per AF saved of 1.53-1.55 times that of a perfect targeting policy.

The results of this study contribute to our knowledge of the impacts of policies aimed at reducing farmer water use. In particular, this is the first study to empirically examine the extent to which water rights retirement programs reduce water use. The results suggest that CREP effectively reduces water use by targeting high water use individuals. The high savings attributable to CREP stand in contrast with the negligible water savings of past policies such as cost-sharing incentives for efficient irrigation systems. The large conservation impact of CREP also contrasts with the impacts of other incentive-based conservation policies in general. The large impact can be attributed to the program's eligibility requirements and a lack of correlation between water use intensity and the value of water rights. This study also contributes to the literature evaluating the cost effectiveness of incentive-based conservation policies. Incentive-based policies such as CREP that increase rates over time are more cost-effective than those that do not. Such policies attract farmers with the lowest value of water first, thus are able to target based on unobserved differences in value. The results also suggest that incentives that target individuals based on data of past water use can be considerably more cost-effective at achieving water savings.

This study's findings have implications for policy makers in water-scarce regions looking to more efficiently manage water. The findings suggest that policy makers can target high-use irrigators in future efforts to reduce stress on water supplies and can at the same time encourage conservation of the least profitable irrigated farmland. It also finds that the current CREP design can be made more cost-effective with some simple changes to the program's incentive designs. The study finds that the current policy's practice of increasing the incentive rates offered over time captures unobserved differences in the value of water rights. Consequently, water managers can use this as an alternative to mechanisms such as auctions as a way to decrease the costs of achieving conservation goals. The simulations also suggest that per-use incentive rates are a potential alternative way to target high-use irrigators. Current eligibility requirements ensure that farmers only enroll intensely irrigated land, but per-use incentives could achieve the same goal by simply paying lower rates to farmers who use little water. Thus future policies could increase the scope of a rights retirement program by using per-use incentives instead of eligibility requirements.

There are a few notable caveats to the findings of this study. First, although it has achieved high water use savings from enrolled rights, CREP has only succeeded in enrolling 145 marginal water rights so far. To make a more substantial impact on aquifer depletion, many more rights will need to be enrolled. Water managers can gradually increase the scope of retirement programs by offering higher incentive rates over time. However, without more insight into the willingness to accept of unenrolled farmers to retire their rights, it would be difficult to determine if water rights retirement programs could actually be a cost effective approach to substantially slow down aquifer depletion. Further, although CREP reduces annual water use over the ten policy years observed, this study is unable to look at the full policy horizon to measure the total water savings of the program. Future research examining the long-term implications of water rights retirements on patterns of aquifer depletion would be interesting. Finally, future work should compare the relative merits of the mechanisms explored in this analysis such as policy rollouts to other policy approaches such as auctions in achieving the most cost-effective water savings. Such work would benefit from a more complete distribution of water rights values and a more detailed analysis of the role of anticipation of rate increases for policies that increase rates over time. Despite these limitations, the results of this study provide strong empirical evidence that water rights retirement programs offer a promising solution to aquifer depletion.

Chapter 9: Household Willingness to Pay for Stream Restoration on Public and Private Land: Evidence from the Baltimore Metropolitan Region

9.1. Introduction

Rivers and streams are vital assets that provide a range of ecosystem services and goods, such as drinking water, recreational opportunities, and aquatic habitat. Stream restoration has emerged as one of the most widely used interventions to improve water quality with over 37,000 stream restoration projects in the United States during 1990-2003 at an estimated total cost of $15 billion (Bernhardt et al. 2005). Streams and their degradation obey no boundaries for land tenure, such that in many urban and suburban areas, the majority of stream miles occur on privately owned land. Our analysis focuses on the Baltimore region where the majority of stream restoration projects have been undertaken on public land, despite the fact that over 80% of the total stream miles are located on private property. In order to comply with the total maximum daily load (TMDL) requirements under the Clean Water Act, there is a growing need to increase restoration activity on private property, as well as continued restoration on public lands. Yet there is limited research on household willingness to pay (WTP) for costly stream restoration efforts in urbanized regions that may occur on both private and public land.

Using the stated preference approach, the literature has analyzed the impact of allowing access on public lands. Johnston and Duke (2007), for instance, use a choice experiment to determine the WTP for agricultural land preservation, finding that allowing public access significantly increases household value particularly for walking and biking activities. Kline and Wichelns (1998) find that public access can impact the value of preserving some land use types, but not others. Johnston et al. (2005) find that resource users value certain types of access to restoration sites more than nonusers. McGonagle and Swallow (2005) analyze how different levels of public access may impact the WTP for the amenities at coastal preservation sites, varying the number of parking spaces at public beaches. They find that households have heterogeneous WTP for public access based on different attitudes for environmental goals and recreational activities, and that high levels of access may actually reduce the willingness to pay of coastal preservation for some individuals living in close proximity to public beaches.

Another important factor is proximity to the resource. Several studies have estimated how distance to a restoration or preservation site affects its values (Bateman et al. 2006; Brouwer, Martin-Ortega and Berbel 2010; Schaafsma, Brouwer and Rose 2012; Jorgensen et al. 2013). Some papers have analyzed the dissipation in WTP over distance, hereafter referred to as distance decay. Others have examined heterogeneity in distance decay in overall willingness to pay for preserving resources for users and nonusers (Sutherland and Walsh 1985; Schaafsma, Brouwer and Rose 2012; Jorgensen et al. 2013). This study is the first to estimate the heterogeneity in distance decay across different types of land ownership of the resource.

In this study, we examine household preferences for stream restoration on private and public land using a choice experiment to elicit the WTP for stream restoration attributes. In each choice experiment, survey participants are presented with a hypothetical stream location being considered for restoration, where land ownership and distance to the stream location vary across choice experiments. The restoration designs include four types of attributes, including near-stream vegetation type in the riparian zone, streambank stabilization and structure, nutrient pollution reduction in local streams and the Chesapeake Bay, and the cost to the household. Using several modeling specifications, we estimate the WTP for these restoration attributes and examine the variation in these estimates by land ownership and distance.

This study makes two main contributions to the literature. First, it identifies which attributes of stream restoration convey value. The restoration attributes of streambank stabilization and nutrient reduction each have a positive and highly significant WTP for all six combinations of land ownership and distance. Households have a one-time marginal WTP for the protection of streambanks using boulders and wetlands ranging from $87.55-153.96 and $82.00-138.47, respectively. Households also have a significant WTP for reducing water pollution in all six situations. On the other hand, changes in near-stream vegetation attributes only have a significant WTP in a few cases. Most notably, the removal of existing trees actually has a significant negative WTP when within walking distance and on private land. Policy makers can use these results to set priorities for choosing which kinds of alterations to make in future restoration projects.

Second, we examine heterogeneity in WTP for restoration projects across several levels of both land ownership and distance. Previous studies have analyzed the value of providing public access to restoration projects, but few studies have examined heterogeneity in the WTP of attributes based on land ownership. This distinction is important because the opportunities for restoration projects on public land are limited and future restoration projects will need to be increasingly implemented on privately owned land. For the addition of boulders, WTP is $59.62 greater on public than private land when within far driving distance. The differences between public and private for boulders and wetland are insignificant when within walking distance. Further, previous studies have explored the role of distance to a resource in evaluating its value but have not examined heterogeneity in WTP based on land ownership and distance. It is often thought that WTP dissipates with distance mainly because of the ease of visiting a site (Bateman et al. 2006). However, our findings suggest that distance decay may sometimes be driven more by nonuse considerations. For instance, on private land we find that WTP for streambank stabilization attributes is significantly greater when comparing streams within walking and driving distance. However, there is no significant distance decay for these same attributes when on public land. In general, our findings suggest that policy makers would benefit from knowledge of heterogeneity in WTP when deciding whether to restore streams on private land, or in less densely populated areas where the local amenity benefits may be relatively small.

9.2. Policy Background on Stream Restoration

Urban development has led to major increases in sediment and pollution loads entering streams and local waterways. Impervious surfaces, such as roads and rooftops, do not absorb rainwater, thereby increasing stormwater runoff and stream flows after heavy rainfall. This puts stress on streams, increasing soil erosion and damaging public infrastructure such as sewer pipes, roads, and bridges. Higher amounts of nutrient pollution in local waterways leads to excessive growth of algae that can negatively affect fish and other aquatic organisms. The Clean Water Act of 1972 regulates discharges from point sources (e.g., wastewater treatment plants), whereas urban stormwater was initially exempt because it was considered a nonpoint source. This changed in 1987 when the United States Environmental Protection Agency (EPA) established the National Pollution Discharge Elimination System (NPDES) stormwater program that required large municipal separate storm sewer systems (MS4s) located in incorporated areas with populations of 100,000 or more to comply with NPDES permits to mitigate the impacts of urban stormwater.

Over the past few decades, efforts to restore the Chesapeake Bay have achieved limited success in improving water quality. Urban development and the associated stormwater runoff in the Bay watershed has been a major contributor of excess nutrient and sediment loads. In 2010, the EPA established the Chesapeake Bay TMDL that set pollution reduction requirements for nitrogen, phosphorus and sediment that must be achieved by 2025. The Bay TMDL is the largest ever developed by the EPA, spanning across portions of six states (Maryland, Pennsylvania, Virginia, Delaware, New York, West Virginia plus the District of Columbia). Urban stormwater management is the most costly sector. The estimated total cost of complying with the TMDL is $14.4 billion in Maryland alone, with $7.3 billion in expected compliance costs to adopt practices in the urban stormwater management sector (MDE 2012a). Nutrient loads from stormwater management are primarily addressed by local governments, who each are required to develop their own watershed implementation plan (WIP) for meeting reduction for their load allocations.

Stream restoration is one of the main approaches used by local governments in the City of Baltimore and Baltimore County to comply with the TMDL. Stream restoration projects absorb nutrients and also are often designed with bank stabilizing features (e.g., boulders, stones) to reduce erosion and potential damage to infrastructure, such as sewer pipes, roads and bridges. Stream restorations can provide aesthetic benefits to communities using vegetation management in the riparian zone, such as tree planting and other features. Baltimore County's WIP states that stream restoration is the most important approach being implemented for meeting long-term nutrient reduction goals, with the proposed plan to expand from 63,174 linear feet in 2013 to 347,000 linear feet by 2025 (MDE 2012b). Stream restoration projects in this region cost approximately $500-1200 per linear foot (Kenney et al. 2012), meaning that Baltimore County plans to spend about $141-340 million on stream restorations alone over this period.

Figure 9.1 shows the 58 stream restoration projects that have already been implemented in Baltimore County and Baltimore City. The majority of these projects have occurred in suburban areas that are located within the municipal sewer service area. Baltimore County has an urban growth boundary, also known as the Urban-Rural Demarcation Line (URDL), which restricts the extension of sewer service to occur within the URDL. Residential development at higher density (> 1 house per acre) is only allowed on sewer service, whereas residential development at lower density (< 1 house per acre) is commonly built on septic systems in the rural area outside the URDL (Newburn and Ferris 2016). Although the area inside the URDL only comprises approximately one-third of Baltimore County's total land area, it contains the vast majority of the county population. Consequently, stream restoration projects mainly occur inside the URDL in Baltimore County, due to higher density and hence more impervious surfaces, where streams are more likely to be degraded.

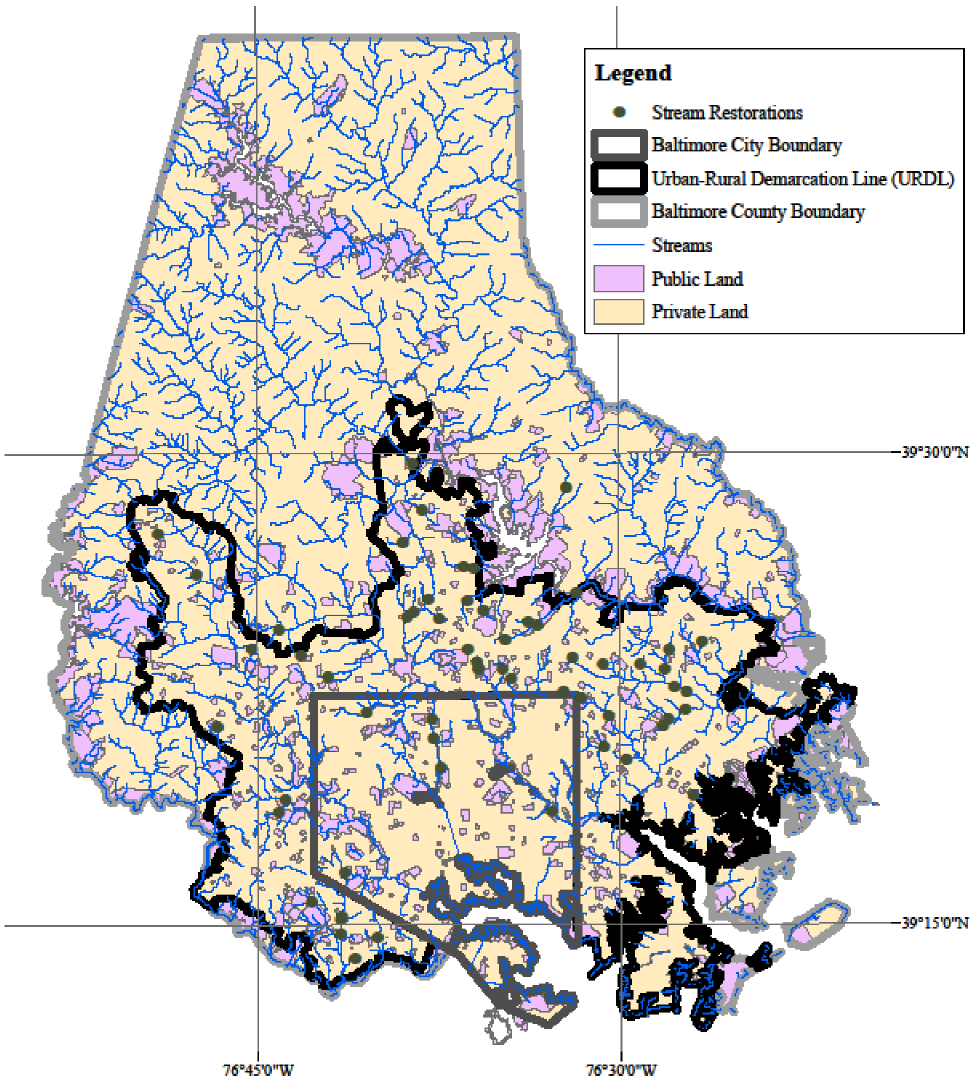


Figure 9.1: Stream restorations on public and private land in Baltimore City and County

Fewer projects have been completed in Baltimore City. The city is completely within the URDL, and urban development occurs primarily at very high density. In fact, the majority of the land area in Baltimore City was built historically at such high urban density that most streams have been buried and flow underground in large stormwater pipes. The small number of restoration projects mainly occur in the outskirts of Baltimore City, where streams are more common, and density is relatively lower. The rural region outside the URDL in Baltimore County also has fewer restoration projects than inside the URDL. Exurban development outside the URDL occurs at lower density such that streams are typically less degraded and are lower priority for restoration. Nonetheless, there is interest in restoration projects outside the URDL because residential development on septic systems have a higher nitrogen load per household.

Figure 9.1 also shows the distribution of streams on public and private lands. Public land includes parks, schools and other publicly owned properties for Baltimore County and Baltimore City, based on the parcel-level tax assessment data from the Maryland Department of Planning. The stream layer shown in Figure 9.1 includes perennial and intermittent streams and rivers from the United States Geological Survey's National Hydrography Dataset (NHD). Many existing stream restorations have occurred at least partially on public land due to easier access for construction. However, the majority of stream miles in Baltimore County and Baltimore City occur on private land. The total stream miles occurring on private land is 82% within the URDL in Baltimore County, 84.4% outside of the URDL, and 60.4% in Baltimore City. Both jurisdictions are expected to increase stream restoration projects to comply with the TMDL requirements and need to understand the relative WTP for restoration activities on public and private lands.

9.3. Econometric Model

In this section, we first outline the three econometric approaches used to estimate our choice model. These include a conditional logit model, a weighted conditional logit model, and a mixed logit model. We then provide a formulation that translates estimated parameters from the econometric models into marginal WTP estimates of stream restoration attributes. This formulation allows us to examine the heterogeneity in the marginal WTP for restoration attributes that potentially vary by land ownership and proximity to households.

Choice experiments are theoretically grounded in a random utility modeling framework, where underlying a discrete choice model is an indirect utility function as in equation 9.1. The utility of a household U_j derived from choice j is the sum of a deterministic component $V(z_j, c_j)$ and a random component observed by the household but not the researcher e_j. The deterministic component is a function of a vector of attributes z_j and a cost to the household c_j. Because income is constant across choices, we do not include income in the specification of U_j (Haab and McConnell 2002). Most studies specify a linear form for the deterministic portion of utility

(9.1) $U_j = V\left(z_j, c_j\right) + e_j = z_j'\beta + \lambda c_j + e_j.$

To estimate a random utility model, as shown in equation 9.1, a conditional logit (CL) model is a commonly used specification in the stated preference literature.

Conditional logit models assume that the error term in equation 9.1 is independently and identically distributed (IID) according to a type I extreme value distribution (Train 2009).

Our second econometric approach, a weighted conditional logit (WCL) model, allows us to account for non-response bias based on observable characteristics of sample respondents and non-respondents. Specifically, the WCL is an inverse probability weighting approach, outlined in detail in Hindsley, Landry and Gentner (2011). A probit model is used to estimate the probability that household i in our sample participates in the survey as a function of observable characteristics q_i for respondents and non-respondents. In our case, we use observable parcel-level housing characteristics from the tax assessor database, surrounding land-use characteristics in the vicinity of each household, and neighborhood-level demographics from census data for both respondents and non-respondents in the sample. The predicted probability of household i participating in the survey given the parcel-level and census tract-level characteristics q_i, is given by $\hat{\pi}(q_i)$. Predicted probabilities for each respondent are then used in the weighted conditional logit model, where the weights are given by equation 9.2

(9.2) $W_i = \frac{1-\hat{\pi}(q_i)}{\hat{\pi}(q_i)}$.

As the probability of responding increases, the weight W_i decreases, meaning that households who are most likely to respond have lower weight in the regression analysis.

Our third econometric approach is a mixed logit (ML) model, also known as a random coefficients logit model. The conditional logit model described in equation

9.1 implies that the probabilities for decisions are mutually exclusive after controlling for observed covariates. This is known as the independence of irrelevant alternatives (IIA) assumption. The mixed logit model relaxes the IIA assumption to some degree, allowing for some correlation across choices for a given household. It adds a random component to the coefficients of observable covariates, fit to a specified probability distribution. The mixed logit model is a commonly used model for choice experiments (Johnston et al. 2005; Brouwer, Martin-Ortega and Berbel 2010; Londoño-Cadavid and Ando 2013), where it is often assumed that taste parameters β_i are normally distributed with mean b and standard deviations given by the diagonal matrix W (Train 2009). This formulation is desirable when there is considerable heterogeneity in tastes for some attributes, in which case any alternatives with similar attribute levels will have correlated random components.

Each of the three models outlined above are estimated using the specification in equation 9.3. In equation 9.3, U_j is the utility received from a particular stream restoration option j. In our choice experiment, z_j contains two types of attributes. First are restoration attributes, which vary across restoration options. These are given by the vector x_j, which includes attribute levels for near-stream vegetation type, streambank stabilization, and nutrient pollution reduction. Second are stream location attributes, which do not vary across restoration options and thus only enter equation 9.3 as interaction terms. These include land ownership and stream proximity, which are considered as being fixed for any particular stream location. A dummy variable for land ownership a takes the value one when the stream is on public land and zero when on private land. Dummy variables for distance d_s and d_f indicate whether the stream location is within a short drive or far drive, respectively, from the household. When both $d_s = 0$ and $d_f = 0$, the stream is within walking distance. Interactions are included between restoration attributes and stream location attributes to allow for heterogeneity in tastes based on different combinations of land ownership and proximity. Three-way interactions between land ownership, distance and restoration attributes allow for further heterogeneity, explained in more detail below. The cost to the household and error terms are defined as before in equation 9.1

$$(9.3) \quad U_j = x_j'\theta + ax_j'\alpha + d_s x_j'\delta_s + d_s a x_j'\gamma_s + d_f x_j'\delta_f + d_f a x_j'\gamma_f + \gamma c_j + e_j.$$

Parameters are more interpretable when transformed into WTP estimates. Based on the results from Hanemann (1984), equation 9.4 provides the formula used in this study to determine the expected marginal WTP for a change in restoration attribute k. This can be calculated as the marginal rate of substitution between the attribute and household cost. It assumes that $-\lambda$ represents the marginal utility of income due to the cost to the household. Thus, the formula for marginal WTP represents the amount of income a household would willingly give up to pay for a marginal change in attribute k

$$(9.4) \quad WTP = -\frac{\frac{\partial V_j}{\partial x_{jk}}}{\frac{\partial V_j}{\partial c_j}} = -\frac{\theta_k + a\alpha_k + d_s\delta_{sk} + d_s a\gamma_{sk} + d_f\delta_{jk} + d_j a\gamma_{jk}}{\lambda}.$$

We are interested in how the marginal WTP of each restoration attribute differs based on land ownership and proximity to the household. This translates into two categories of hypotheses to test. The first is whether the marginal WTP for a restoration attribute differs on public and private land, conditional on the distance and other attributes. The second is whether the marginal WTP for a restoration attribute differs with distance, conditional on the land ownership and other attributes.

First, consider an example of a hypothesis test for the difference between public and private land, conditional on proximity. If a household is within walking distance to a stream restoration on publicly owned land, the marginal WTP for restoration attribute k is equal to $-\frac{\theta_k+a\alpha_k}{\lambda}$ If a household is within walking distance to a stream being restored on private land, the marginal WTP for this attribute is $-\frac{\theta_k}{\lambda}$. The difference between these two terms on public and private land is then $-\frac{a\alpha_k}{\lambda}$, which can be viewed as the "public premium" for attribute k for a stream within walking distance. A similar calculation based on equation 9.4 can also be used to determine the public premium for a stream within a short or far drive.

The estimated public premium for attribute k is more likely to be significant for some distances than for others, depending on how households care about land ownership. One reason for a public premium could be that public land allows for site visitation, while private land does not. If a site is far away, the residents are less likely to visit a stream on either public or private land. In this case, site visitation will lead to a public premium that is largest when within walking distance. On the other hand, residents may value restoration for any public or private locations in their neighborhood; however, at farther distances, they only value restoration on public lands in the region. This would suggest that they will have similar WTP for public and private sites in their neighborhood, but will have a public premium for restoration sites that are within driving distance.

Second, consider how the marginal WTP for restoration attribute k may vary with proximity, conditional on land ownership. Again, if a household is within walking distance of a stream being restored on public land, the marginal WTP for restoration attribute k is $-\frac{\theta_k + a\alpha_k}{\lambda}$. If that same household is within short driving distance of a stream being restored on public land, the marginal WTP for restoration attribute k is $-\frac{\theta_k + a\alpha_k + d_s\delta_{sk} + d_s a\gamma_{sk}}{\lambda}$. The difference between these terms is $\frac{d_s\delta_{sk} + d_s a\gamma_{sk}}{\lambda}$, which can be viewed as the distance decay in WTP for attribute k between streams within walking distance versus a short drive, conditional on the stream being on public land. Similar calculations could be used to estimate distance decay, conditional on private land.

The discussion provided above for a significant public premium may also explain the different patterns in distance decay by landownership type. Because site visitation is only allowed on public land, this mechanism would explain distance decay on public but not private land. Meanwhile, if residents value stream restoration similarly on both public and private land in their immediate neighborhood, but only maintain higher support for restoration on public land for streams that are further away, then distance decay may only occur on private land. The assessment of differences in WTP for stream restoration attributes by land ownership and distance is an empirical issue to be tested. In the next section, we provide details on our survey instrument for the choice experiment, followed by the empirical regression analysis and WTP estimates for the various restoration attributes by ownership and distance.

9.4. Household Survey Design and Data

9.4.1. Data

The survey was conducted in the Baltimore metro region, including the two local jurisdictions of Baltimore County (pop. 831,128) and the City of Baltimore (pop. 621,849). The Baltimore metro region is large and diverse, ranging from dense urban communities to rural residential areas. The TMDL requirements have led to large-scale efforts to implement urban stormwater management strategies targeted at reducing nutrient and sediment loads.

To construct the sample population, we limited the sampling region to neighborhoods where stream restoration projects are likely to be implemented in the Baltimore metro region. As noted above, the inner core of downtown Baltimore City mainly has very high density development where restoration projects are not suitable because most streams are buried in stormwater pipes. To screen out these neighborhoods, we overlaid the existing restoration projects in Figure 9.1 with the census tract boundaries for the Baltimore City and area inside the URDL for Baltimore County. We estimated a probit regression model at the census tract level, where the dependent variable is whether the census tract has a restoration project and is modeled as a function of population density, urban land cover, stream density and other variables. We screened out any census tract where the predicted probability of restoration is less than 1%, which occurred almost exclusively in the dense area of downtown Baltimore City and along major interstate highway corridors. For the rural region outside the URDL, we only included residential properties where the lot size is smaller than five acres, which screens out the rural properties in agriculture, forestry, and other uses.

The sample for the household survey was drawn from the population of single-family homeowners in Baltimore County and Baltimore City, using the complete parcel-level tax assessor database from the Maryland Department of Planning. After the screening process above, 9.0% of all households in the sample region were outside the URDL in Baltimore County, 67.7% inside the URDL in Baltimore County and 23.3% in Baltimore City. We stratified the sample to ensure a sufficient number of households in the rural area outside of the URDL in Baltimore County. Specifically, a stratified random sample of 11,000 single family residential homeowners was drawn from the three regions: outside the URDL in Baltimore County (25%), inside the URDL in Baltimore County (50%), and Baltimore City (25%), where sampling was done with known weights since we have the complete tax assessor database.

The survey design was informed based on detailed discussions with policy makers and academic experts in stream restoration. We interviewed hydrologists, ecologists, engineers and government agency staff from Baltimore County and City to properly describe and present restoration design attributes and other questions based on recent restoration projects in the study region. We then pretested the survey extensively on local residents to improve the clarity and revise the questionnaire accordingly. The survey was administered in September and October 2017, using an address-based sampling approach (Johnston et al. 2017), where recruitment letters to complete the survey online were sent by mail using addresses obtained from the parcel-level tax assessor database. The letters included instructions for completing the survey online on Qualtrics, and a follow-up reminder letter was mailed several weeks later. We also included a raffle for Amazon gift cards awarded to six randomly selected respondents to increase the response rate. Each respondent was assigned a unique identification code and password to login into the online survey. The unique code was matched to their street address, allowing us to know the household's location for inclusion of geospatial data in the analysis. Recruitment letters also provided an email address and phone number to allow the household to arrange for the option to have a paper copy of the survey mailed to them. Of the 11,000 households in the survey sample, we received 963 online responses and 54 surveys were completed by mail, a response rate of 9.2%. Most, but not all, respondents completed all four choice questions, leaving a total of 4,004 usable choice experiments. Three respondents were removed due to missing housing characteristics or census demographic data, leaving 3,992 choice experiments for the regression analysis.

9.4.2. Survey Design

The survey questionnaire initially provided background information on stream restorations. Respondents were shown photographs with descriptions to explain how urban development and impervious surfaces creates conditions for increased stormwater volume and velocity, leading to stream bank erosion, infrastructure damage, sewer leakage, and downstream water pollution. Respondents were then asked about their prior knowledge of stream restorations and their recreational activities for local parks, streams, and the Chesapeake Bay. After a section describing the different attributes of stream restoration, the four separate choice experiment questions were presented to each respondent. Finally, the survey concluded with demographic questions.

Each respondent received four choice experiment questions, relating to a hypothetical stream with one of six possible combinations of land ownership and proximity. Each choice question included two possible stream restoration options and a third option for choosing to remain in the current situation (i.e., no restoration). Figure 9.2 provides an example of one choice experiment question. The choice experiment describes the stream location attributes for the land ownership and proximity to the household, which are the same for all three restoration options for a given hypothetical stream location. The restoration attributes for the three options are provided, where the status quo option always has the same baseline attributes.

Table 9.1 summarizes the stream location and restoration attributes and their levels. Stream location attributes describe the land ownership and proximity variables. For land ownership type, a stream can be on public or private land. Respondents were told that only public land is accessible, whereas restoration on private property does not allow access. Proximity of the hypothetical stream location was set as one of three levels— within walking distance (less than a mile), short driving distance (1-5 miles), or far driving distance (greater than 5 miles). Land ownership and distance attributes varied across but not within choice experiment questions. Each respondent was randomly given four of the six possible combinations of the ownership and distance attributes in the four choice experiments provided.

D1. Restoration projects A and B are two possible options to restore a **1000 foot** section of a degraded stream (about the length of 3 football fields). The "current situation" means no restoration project will be done at this stream location and no costs are expended. The stream is **not publicly accessible** (on someone's private property) and **within driving distance from your home** (more than 5 miles away). Which of the three options below would you vote for?

Please consider this as if it were a real world example. This is not currently related to any ballot issue that you will vote for in any election, but it could be informative for actual decisions on restoration projects in your area.

	Current Situation (no restoration)	Restoration Project A	Restoration Project B
Location of Stream	This stream is **not publicly accessible** (on someone's private property) And it is **within driving distance from your home** (more than 5 miles away)		
Near-Stream Vegetation	Forest and Meadow Mixed Land left as it is	Forest and Meadow Mixed Land left as it is	Forested Trees planted
Appearance of Stream	No Changes Made Erosion and infrastructure damage will worsen	Wetland Added Provides wildlife habitat, reduces erosion	Boulders and Stones Added Protects infrastructure, reduces erosion
Stream & Bay Pollution Reduced	Meets 0% of goal for water zone For yearly pollution reduction	Meets 40% of goal for water zone For yearly pollution reduction	Meets 30% of goal for water zone For yearly pollution reduction
One-Time Cost to Your Household	$0	$50	$35

Figure 9.2: Example choice question

Restoration attributes include near-stream vegetation, streambank stabilization, stream and bay pollution reduced, and the one-time household cost. Other than the one-time household cost c_j, these restoration attributes correspond to the vector x_j in equation 9.3. Near-stream vegetation has mixed forest and meadow as the status quo for existing vegetation in the riparian buffer zone. Restoration options include forested (planting new trees), meadow (removing trees), and unchanged for maintaining vegetation as mixed forest and meadow. For streambank stabilization, the status quo level is to leave stream banks unchanged, such that they are susceptible to further erosion and potential infrastructure damage when left unprotected. Restoration options include two of the most common approaches to stabilize stream banks. Adding boulders and stones along a stream bank hardens and protects the stream banks from erosion and reduce stream migration that may damage roads, bridges and buried sewer lines that often run along streams. Wetlands provide wildlife habitat in addition to helping to mitigate erosion from excess stormflows.

Table 9.1: Attributes and Levels of Choice Questions

Restoration attribute	**Status quo levels**	**Restoration project levels**
Near-stream vegetation	Forest and meadow mixed	Forest and meadow mixed Meadow Forested
Streambank stabilization	No changes made	No changes made Boulders and stones added Wetland added
Stream and bay pollution reduced	Meets 0 % of goal for water zone	Meets 10 % of goal for water zone Meets 20 % of goal for water zone Meets 30 % of goal for water zone Meets 40 % of goal for water zone Meets 50 % of goal for water zone Meets 60 % of goal for water zone
One-time cost to your household	$0	$10 $20 $35 $50 $75 $100
Stream location attribute	**Levels**	
Stream access	Not publicly accessible (on someone's private property) Publicly accessible (at a park, school, or along the road)	
Proximity to stream	Walking distance (within 1 mile) Driving distance (1-5 miles) Driving distance (>5 miles)	

Finally, stream and bay pollution reduction is a metric capturing the extent to which the stream restoration is able to meet regional goals for satisfying TMDL allocations. Determining levels for pollution reduction used the following approach. In the survey, respondents were told that the county has to reduce its water pollution each year, and the total county goal is split into 12 similarly sized water zones. These water zones are the 8-digit hydrologic unit code (HUC) watersheds as classified by the United States Geological Survey (USGS) that are used in the county WIP. Pollution reduction levels were determined by considering estimated effects on nitrogen from restorations in the county WIP, and determining how much of the yearly goals this would meet. Because there is a large range of possible effects of restorations on water quality, this calculation was used simply to make sure the provided levels were in the appropriate range of values. By framing water quality improvements as part of an overall yearly county plan, local residents can have a better understanding of the restorations as they relate to water quality improvements in the Chesapeake Bay. This was partly an attempt to address the well-known embedding problem associated with valuations of different scales of environmental improvements (Kahneman and Knetsch 1992).

Experimental design involves choosing which attributes to combine into alternatives and which combinations of alternatives to put into choice sets (or choice questions). We generated choice sets using a SAS Macro that uses a D-optimality criterion, as described in Kuhfeld (2005). It uses an algorithm that minimizes the variance of a conditional logit model where the parameters are all assumed to equal zero (Kuhfeld 2005). This approach consistently provides the most efficient choice designs when enough choice sets are used (Lusk and Norwood 2005). To avoid restoration choices that did not involve any intervention, attributes were restricted so that for all restoration choices, at least one of near-stream vegetation and stream stabilization changed from their status quo levels. This process was used to generate 36 unique choice sets. Each unique choice set was combined with one of the six combinations of land ownership and proximity to a stream to make 216 choice sets. These were then split into 54 blocks, where the four choice sets included in each block were ordered randomly. Using the randomizer tool in Qualtrics, blocks were then assigned randomly and evenly as respondents completed the survey.

9.5. Results

9.5.1. Sample Selection

Before discussing the main results of the survey, it is important to assess whether there are systematic differences between the survey respondents and non-respondents in order to understand whether non-response bias may affect the regression analysis and WTP estimates. Table 9.2 provides the regression results for a probit model estimating the propensity to respond to the survey. We include three categories of observable characteristics available for non-respondents and respondents. First, we include parcel-level housing characteristics from the Maryland Department of Planning. Second, we include characteristics for the surrounding land use in the vicinity of each parcel in the sample. We calculate the proportion of surrounding forest, agriculture and highly developed land, respectively, within a mile buffer of each household, using the Chesapeake Bay Program Land Cover Data. The distance to the closest stream to each household was determined in ArcGIS using the USGS NHD stream flowline layer. Distance to the closest public land to each household was also determined in ArcGIS using layers from the Maryland Department of Planning. Finally, demographic characteristics are included at the census tract level. There are 49 sampled individuals, including three survey respondents, removed from this analysis in Table 9.2 due to missing information on housing characteristics or census demographic data.

Table 9.2: Probit Model of Participation in Survey

Variables	(1) Coefficient	(2) Standard error
Parcel-level housing characteristics		
Lot size (acres)	0.0229	0.0215
House size (1000 sq ft)	0.0048	0.0249
Structure quality[a]		
Good	0.1790***	0.0479
Very good	-0.0345	0.1728
Year structure built[b]		
1950-1975	-0.0512	0.0453
1975-2000	-0.1560***	0.0533
2000-present	-0.1000	0.0760
Surrounding land use/land cover		
Proportion forest within 1 mile of household	0.0581	0.1645
Proportion agricultural within 1 mile of household	0.0658	0.1687
Proportion highly developed within 1 mile of household	-0.2138	0.1982
Distance to public land (miles)	-0.0771	0.0569
Distance to stream (miles)	0.0740	0.1118
Census tract-level demographics		
Head of household has bachelors proportion	0.3135**	0.1405
Median household income ($1000)	-0.0004	0.0007
Not worked in past year proportion	0.1445	0.3477
Head of household racial minority proportion	-0.3597***	0.0775
Age of head of household	-0.0050	0.0048
Household size	-0.0945	0.0775
Constant	-0.9013***	0.3495
Observations	10,951	
X^2	173.7	

*** p<0.01, ** p<0.05, * p<0.1

[a] Default category for structure quality is poor

[b] Default category for year structure built is before 1950

Results from the probit regression shown in Table 9.2 suggest that some characteristics differ between respondents and non-respondents. For instance, households with high quality housing structures are more likely to respond; however, the housing structure size is not statistically significant. All variables on surrounding land uses in forest, agriculture and high urban development, as well as the distances to public land or streams, are not statistically significant for the probability of survey response. For the census-level demographic characteristics, households located in census tracts with a higher proportion of households with a bachelor's degree are more likely to respond. Furthermore, there is a lower likelihood of response for those households in census tracts with a higher proportion of minority heads of household. The age of head of household and household size are not statistically significant at the census tract level. Median household income at the census tract level is not statistically significant.

Due to these significant differences between the parcel-level housing characteristics and census-level demographic characteristics for respondents and non-respondents, there is the potential for sample selection bias in the model estimation. For this reason, we estimate a WCL model to account for sample selection, based on the weights described in equation 9.2. While we are able to control for self-selection based on observable factors, as shown in Table 9.2, we should acknowledge that there may be unobserved factors that exist as well. This should be taken into account when interpreting the estimation results below, and the WCL model is mainly used to reduce the potential issues from sample selection.

9.5.2. Estimation Results

Table 9.3 shows the estimation results for the conditional logit model, weighted conditional logit model, and mixed logit model, based on the random utility model specification from equation 9.3. Tests of joint significance of all parameters are highly significant for all three models. Estimated coefficients for the CL and WCL models are provided in columns 1 and 3, respectively. The WCL model is preferred to the CL model because it reduces the potential non-response bias. For the ML model, the estimated coefficients for the mean and standard deviation parameters are provided in columns 5 and 7, respectively. While the most flexible ML model specification would allow for a random distribution for the entire vector of parameters, in practice this may lead to challenges for model convergence due to the large number of random parameters (Layton 2000; Hensher and Greene 2003). For this reason, the parameters for the five main restoration attributes, θ in equation 9.3, are specified to be random in the ML model, and all other parameters for the 25 interaction terms with distance and land ownership are specified as fixed parameters. A Wald test of the joint significance of standard deviation parameters in the ML model shows that it provides a significantly better fit than the CL model. The ML model is preferred to the CL model since it allows for preference heterogeneity for households, as indicated by the significance in the estimated standard deviation parameters for the restoration attributes. Note that the estimated mean coefficients in Table 9.3 are scaled higher in the ML model as expected compared to the CL and WCL models, but the WTP estimates are similar.

Table 9.3: Results of Conditional Logit, Weighted Conditional Logit and Mixed Logit Models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	CL	SE	WCL	SE	ML-Coef	SE	ML-SD	SE
Meadow	-0.387***	(0.124)	-0.412***	(0.134)	-0.669***	(0.211)	-1.272***	(0.160)
Forest	-0.018	(0.113)	-0.084	(0.124)	0.017	(0.176)	0.675***	(0.171)
Boulders	1.305***	(0.125)	1.486***	(0.134)	2.200***	(0.214)	1.355***	(0.167)
Wetland	1.153***	(0.123)	1.321***	(0.137)	2.004***	(0.197)	0.915***	(0.167)
Nutrients	0.024***	(0.003)	0.024***	(0.003)	0.045***	(0.006)	-0.060***	(0.004)
Cost	-0.010***	(0.001)	-0.010***	(0.001)	-0.018***	(0.002)		
Access X Meadow	0.376**	(0.183)	0.505**	(0.204)	0.642**	(0.306)		
Access X Forest	0.127	(0.159)	0.287*	(0.172)	0.154	(0.251)		
Access X Boulders	0.180	(0.174)	0.106	(0.183)	0.296	(0.284)		
Access X Wetland	0.200	(0.171)	0.112	(0.188)	0.233	(0.252)		
Access X Nutrients	0.002	(0.004)	0.001	(0.005)	0.006	(0.007)		
Short Drive X Meadow	0.487***	(0.172)	0.502***	(0.189)	0.937***	(0.292)		
Short Drive X Forest	0.182	(0.158)	0.182	(0.175)	0.461*	(0.239)		
Short Drive X Boulders	-0.196	(0.164)	-0.365**	(0.183)	-0.367	(0.269)		
Short Drive X Wetland	-0.124	(0.159)	-0.279	(0.178)	-0.290	(0.232)		
Short Drive X Nutrients	-0.008*	(0.004)	-0.006	(0.005)	-0.014*	(0.007)		
Far Drive X Meadow	0.433**	(0.179)	0.444**	(0.195)	0.835***	(0.305)		
Far Drive X Forest	0.037	(0.161)	0.110	(0.178)	0.132	(0.250)		
Far Drive X Boulders	-0.446***	(0.171)	-0.581***	(0.186)	-0.762***	(0.279)		
Far Drive X Wetland	-0.301*	(0.170)	-0.472**	(0.189)	-0.515**	(0.252)		
Far Drive X Nutrients	-0.003	(0.004)	-0.002	(0.004)	-0.009	(0.007)		
Access X Short Drive X Meadow	-0.256	(0.256)	-0.491*	(0.281)	-0.500	(0.428)		
Access X Short Drive X Forest	-0.013	(0.227)	-0.091	(0.255)	-0.108	(0.352)		
Access X Short Drive X Boulders	0.034	(0.234)	0.123	(0.253)	0.104	(0.389)		
Access X Short Drive X Wetland	0.081	(0.235)	0.177	(0.263)	0.264	(0.349)		
Access X Short Drive X Nutrients	0.012**	(0.006)	0.009	(0.006)	0.021**	(0.010)		
Access X Far Drive X Meadow	-0.226	(0.264)	-0.394	(0.295)	-0.358	(0.440)		
Access X Far Drive X Forest	0.165	(0.237)	-0.015	(0.264)	0.263	(0.373)		
Access X Far Drive X Boulders	0.377	(0.234)	0.511**	(0.254)	0.736*	(0.387)		
Access X Far Drive X Wetland	0.215	(0.234)	0.361	(0.260)	0.433	(0.347)		
Access X Far Drive X Nutrients	0.004	(0.006)	0.008	(0.007)	0.007	(0.010)		
Observations	11,976		11,976		11,976			
Wald test p-value (joint test)[a]	0.0000		0.0000		0.0000		0.0000	

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors in parentheses. Standard errors are clustered at the individual household level for each model. There are 3992 usable choice sets included in the regression, with three choices per choice set.

[a] Wald tests are performed for joint significance of parameters. The test in column (7) tests the joint significance of the standard deviation parameters in the ML model.

We use the estimation results in Table 9.3 to derive marginal WTP estimates for each attribute of stream restoration for the WCL model (Table 9.4) and ML model (Table 9.5) and CL model (Table 9.6), respectively. The marginal WTP estimates for each restoration attribute calculated based on equation 9.4, conditional on each of the possible combinations of land ownership and distance. The marginal WTP for nutrient reduction is the value of achieving a 1% reduction in nutrient pollution for the local water zone. The marginal WTP for the other restoration attributes represent a discrete change from the baseline status quo category, given that streambank stabilization and near-stream vegetation attributes are categorical variables. All standard errors are calculated using the delta method.

We focus here on the WTP estimation results for the WCL model in Table 9.4 in the discussion below. In Table 9.4, boulders and wetland have a significant positive marginal WTP regardless of land ownership and distance. This finding suggests that people have a high WTP for stabilizing eroded streams, even ones they will not likely visit. However, the range of values is considerable. The WTP for streambank stabilization by placement of boulders ranges from $87.55 to $153.96. The WTP for wetlands ranges from $82.00 to $138.47. The marginal WTP for nutrient reduction is also positive and highly significant for each combination of land ownership and proximity. This last result suggests that residents value water quality improvement in local streams and the Chesapeake Bay and have a strong preference to improve its water quality regardless of where the improvements are being made.

On the other hand, meadow and forest are less likely to have a significant marginal WTP. Households have a significant positive WTP for the addition of forests when on public land and within a short or far driving distance. However, these estimates are considerably smaller in economic significance compared to those for streambank stabilization and nutrient reduction. This likely has much to do with the status quo (and default) category for streamside vegetation. Apparently, people do not have strong preferences between a mixed landscape (the status quo), forest and meadow. Further, there is a significant negative WTP associated with meadow when on private land within walking distance. The negative marginal WTP suggests that meadows can be unpopular on private land since it involves removal of existing trees from the status quo on mixed forest and meadow.

Table 9.4: Marginal WTP of Restoration Attributes for Weighted Conditional Logit Model

	(1) Walk	(2) Short Drive	(3) Far Drive	(4) Walk - Short Drive	(5) Walk - Far Drive
Boulders					
Public	153.96***	130.58***	147.17***	23.38	6.79
Private	143.71***	108.40***	87.55***	35.31*	56.16***
Public-Private	10.25	22.18	59.62***		
Wetland					
Public	138.47***	128.57***	127.66***	9.90	10.81
Private	127.68***	100.70***	82.00***	26.98	45.68**
Public-Private	10.79	27.87	45.66**		
Nutrients					
Public	2.36***	2.67***	2.95***	-0.31	-0.59
Private	2.30***	1.73***	2.12***	0.57	0.18
Public-Private	0.06	0.94**	0.83*		
Forest					
Public	19.64	28.41**	28.80**	-8.77	-9.16
Private	-8.10	9.50	2.54	-17.60	-10.65
Public-Private	27.75*	18.91	26.26		
Meadow					
Public	9.04	10.06	13.93	-1.02	-4.89
Private	-39.80***	8.72	3.15	-48.52***	-42.95**
Public-Private	48.84**	1.33	10.78		
Observations	11976	11976	11976	11976	11976

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: There are 3992 usable choice sets included in the regression, with three choices per choice set.

For boulders, Table 9.4 shows some important differences between WTP of restoration attributes on public and private land. Specifically, in Table 9.4, households have a $59.62 public premium for boulders when they are a far drive away, significant at the 1% level. If the primary reason for a public premium has to do with access, then the public premium should be highest when within walking distance. However, boulders only have a public premium when they are a far drive away from households. Table 9.4 also shows some significant differences in WTP across distances, conditional on land ownership. For boulders and wetland, there is a significant distance decay for restorations on private land but not on public land. For stream restorations on private land, households are willing to pay $35.31 and $56.16 more for boulders when within walking distance compared to within a short drive and far drive, respectively. Further, households will pay $45.68 more for wetlands within walking distance versus far driving distance. The values for distance decay of both boulders and wetland are positive for restorations on public land, but never significant. Taken together, the results for public premiums and distance decay of stream appearance suggest that people value improvements to streams in their neighborhood regardless of land ownership, but care less about private streams outside of their neighborhood.

Land ownership and distance also have an important effect on the WTP for other restoration attributes. When within walking distance of a stream, households place a significant public premium on both meadows and forest. For the addition of trees, households will pay a $27.75 public premium for a stream within walking distance, significant at the 10% level. Households will pay $48.84 more for a meadow if it is part of a stream restoration on publicly owned land, a difference which is significant at the 5% level. This is driven by the significant negative marginal WTP for meadow on private land within walking distance. Further, there is a significant negative distance decay for meadows on private land. However, again this is driven by the negative WTP of meadow within walking distance. Finally, when within a short and far drive the public premiums for nutrient reduction are positive and significant at the 5% and 10% levels, respectively. However, there is no significant distance decay for nutrient reduction on public or private land. This is not that surprising as the value of nutrient reduction is largely non-local and would not be expected to exhibit significant distance decay.

The WTP estimation results for the ML and CL model in Tables 9.5 and 9.6 respectively are largely similar to those in Table 9.4, suggesting that the main results are robust to the different model specifications that account for non-response bias or individual heterogeneity. Results for the marginal WTP of restoration attributes using the ML model, shown in Table 9.5, are largely similar to those from the WCL model. As with the WCL model, WTP for boulders, wetland and nutrient reduction are significant across all combinations of land ownership and distance. However, the results in Table 9.5 for public premiums and distance decay of boulders and wetland have slight differences. For example, the public premium for wetlands is significant within both a short and far drive. Further, distance decay is only significant for boulders for restorations on private land within a far drive. Despite these differences, the conclusions are largely the same. People place similar value on restorations in their neighborhood regardless of land ownership, but care more about public streams that are within driving distance.

Table 9.5: Marginal WTP of Restoration Attributes for Mixed Logit Model

	(1) Walk	(2) Short Drive	(3) Far Drive	(4) Walk - Short Drive	(5) Walk - Far Drive
Boulders					
Public	141.84***	126.90***	140.40***	14.94	1.44
Private	125.02***	104.16***	81.73***	20.86	43.29***
Public-Private	16.82	22.73	58.67***		
Wetland					
Public	127.15***	125.67***	122.48***	1.48	4.67
Private	113.88***	97.42***	84.59***	16.47	29.29**
Public-Private	13.27	28.25**	37.89**		
Nutrients					
Public	2.90***	3.30***	2.80***	-0.40	0.10
Private	2.55***	1.76***	2.04***	0.79*	0.51
Public-Private	0.35	1.54***	0.76*		
Forest					
Public	9.74	29.80***	32.19***	-20.06	-22.45
Private	0.96	27.18***	8.48	-26.23*	-7.52
Public-Private	8.78	2.61	23.71		
Meadow					
Public	-1.53	23.33*	25.58**	-24.86	-27.11
Private	-38.04***	15.22	9.42	-53.26***	-47.46***
Public-Private	36.51**	8.12	16.16		
Observations	11976	11976	11976	11976	11976

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: There are 3992 usable choice sets included in the regression, with three choices per choice set.

Results from Tables 9.4 through 9.6 have two main policy implications regarding stream restoration. First, our findings suggest that people place considerable value on improvements in stream appearance and nutrient reduction, but less so on changes to streamside vegetation. Policy makers might combine this finding with cost information for proposed projects to determine if the benefits are significant enough to warrant the alteration of the riparian zone. Notably, many past stream restoration projects have made significant changes to the riparian zones of degraded streams. Our findings suggest that such alterations may be warranted if they are an efficient way to reduce erosion and nutrients, but that they do not bring considerable value on their own. In general, our findings suggest that policy makers may want to prioritize measures that improve stream appearance and nutrient reduction, and focus less on expected ancillary benefits from the alteration of the landscape.

Table 9.6: Marginal WTP of Restoration Attributes for Conditional Logit Model

	(1) Walk	(2) Short Drive	(3) Far Drive	(4) Walk - Short Drive	(5) Walk - Far Drive
Boulders					
Public	147.44***	131.39***	140.65***	16.05	6.79
Private	129.59***	110.15***	85.35***	19.44	44.24**
Public-Private	17.85	21.24	55.30***		
Wetland					
Public	134.29***	129.96***	125.74***	4.33	8.55
Private	114.45***	102.12***	84.56***	12.33	29.89*
Public-Private	19.83	27.84*	41.17**		
Nutrients					
Public	2.67***	3.09***	2.84***	-0.42	-0.17
Private	2.43***	1.66***	2.17***	0.77*	0.26
Public-Private	0.24	1.43***	0.67		
Forest					
Public	10.84	27.61**	30.91***	-16.77	-20.07
Private	-1.79	16.25	1.91	-18.03	-3.69
Public-Private	12.63	11.37	29.01*		
Meadow					
Public	-1.05	21.82	19.59	-22.87	-20.63
Private	-38.42***	9.90	4.61	-48.31***	-43.03**
Public-Private	37.37**	11.93	14.98		
Observations	11976	11976	11976	11976	11976

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: There are 3992 usable choice sets included in the regression, with three choices per choice set.

Second, although people have a significant WTP for changes in stream appearance across all combinations of land ownership and distance, there are significant differences in WTP across these combinations as well. Due to the differences in value between restorations on public versus private land, officials may want to consider whether the considerable extra costs associated with purchasing easements or obtaining the rights to build on private land is worth it. Most existing restorations have been placed on streams going through public land or through properties where access to land can be gained at a low cost. Our results support this practice, finding that in addition to lower costs of access, restorations on public land bring significantly higher value. On the other hand, the high WTP for streambank stabilization and nutrient reduction in all situations suggests that policy makers may be justified in restoring streams on private land as may become a requirement in the near future. Further, because WTP is significant for stream appearance and nutrient reduction even at far distances, decision makers could create value from stream restoration in less densely populated areas.

9.6. Conclusion

TMDL requirements have required local and state governments to allocate considerable financial resources to improve water quality, particularly from urban stormwater runoff. Policy makers often have to consider that a large portion of the land in highly developed areas is privately owned and that improving water quality requires restoration on private land. This makes it essential to know how benefits from stream restoration vary between private and public land. In this study, we estimate the household WTP of several different stream restoration attributes on various combinations of land ownership and proximity to stream restoration.

We find that comparing the value of restoration on public and private land depends both on which attributes are changed and how far away the restoration occurs from households. We find that boulders, wetlands and pollution reduction are all valued significantly on both private and public land. These attributes also display considerable variation in WTP across different levels of land ownership and distance. For example, using boulders for bank stabilization on public land within walking distance has a WTP that is almost twice as high compared to using boulders on private land that is a far drive away. In contrast, the near-stream vegetation attributes are less economically significant. Within walking distance on private land, households actually have a significant negative WTP for meadow.

We also find significant heterogeneity in WTP for stream restoration attributes across different levels of land ownership and distance to a stream. Boulders and wetlands exhibit significant public premiums within driving distance but not within walking distance. We also find that, for stream stabilization attributes, distance decay occurs on private land but not on public land. Taken together, these results suggest that households have a similar WTP for stream restorations between public and private land in their neighborhoods, but have a public premium for far away restorations. Finally, we find that the addition of a meadow exhibits a significant public premium within walking distance but not within driving distance.

Our findings about WTP of stream restoration attributes across combinations of land ownership and distance play an important role in policy decisions about where to restore streams. When combined with detailed project cost information, the WTP results of this study could provide important insight for assessing which projects will prove most beneficial. In particular, our findings suggest that policy makers may want to prioritize stream restorations that improve streambank stabilization and nutrient reduction. Although changes in riparian vegetation may have a valuable influence on erosion and pollution, they do not bring significant value by themselves.

Further, it is clear that to satisfy water quality regulations such as the TMDL requirements and NPDES permits for stormwater management, local governments must find cost effective ways to use both public and privately owned land. Costs of projects may differ substantially for projects on public and private land, and the cost-effectiveness of achieving nutrient goals will likely vary across the landscape. To some extent, the issue of private land can be dealt with by using rebates for voluntary household BMPs, such as rain gardens and rain barrels (Thurston et al. 2010; Ando and Freitas 2011; Newburn and Alberini 2016). However, given the extent of degradation in urban streams, and future plans to restore them, it is essential to know when residents have substantial WTP for restoration on public and private land. Our findings show that although several attributes of restorations are valued considerably on private land, the WTP for these attributes is sometimes significantly higher when on public land. Whether policy makers want to restore private streams or streams in sparsely populated areas, they will want to consider heterogeneity in WTP in addition to project costs.

Chapter 10: Stream Restoration Survey

10.1. Additional Survey Response Statistics

The following section provides a more in-depth analysis of survey respondents than is provided in chapter nine. Table 10.1 provides survey response rates for each of the three regions in the Baltimore metropolitan area that were included in the sample. As explained above, the sample was stratified so that 50% of the letters were mailed to households in Baltimore County within the URDL and the remaining 50% were split evenly between Baltimore County outside the URDL and Baltimore City. However, only 18.9% of the total usable choice experiments came from respondents from Baltimore City and 34.2% came from respondents from outside the URDL. This means that households in Baltimore City had a below average response rate compared to the entire sample and the region outside the URDL had an above average response rate. In chapter nine, we use probability weights to estimate population-level parameters in our choice model based on observable characteristics of respondents. Thus we assume that any differences in response rates observed between the three stratified regions can be explained by observable characteristics.

Table 10.1: Survey Respondents by Sampling Region

Sampling Region	Baltimore City	Baltimore County (Inside URDL)	Baltimore County (Outside URDL)	Total
Respondents (#)	191	479	347	1017
Usable Choice Experiments (#)	757	1877	1370	4004
Usable Choice Experiments (%)	18.9	46.9	34.2	100
Full Sample (# of Households)	2750	5500	2750	11000
Full Sample (% Households)	25	50	25	100

We now consider if there are any systematic differences in observable characteristics between survey respondents and non-respondents. To account for such differences, chapter nine uses a probit regression model to predict response probabilities for each respondent that are then included as probability weights in estimating a conditional logit model. In table 10.2, we provide differences in means of various household characteristics for all survey respondents and non-respondents with available data. The table further motivates the importance of controlling for non-response bias in chapter nine. First we look at differences in parcel characteristics. On average, survey respondents have significantly larger parcels and houses. Respondents also have houses of higher structural quality on average. Notably, differences in structural quality do not result from differences in structure age. Further, the years in which structures were built are similar between respondents and non-respondents. Next we look at differences in surrounding land use for households included in the survey. Respondents tend to have more surrounding forest and agricultural land and less surrounding developed land than non-respondents. This difference corresponds with the higher response rate of households outside of the URDL. Finally, there are several significant differences between the two groups in census tract-level demographic variables. Respondents tend to live in census tracts with a higher proportion of householders with a bachelor's degree. They also tend to be in census tracts with higher average incomes, fewer unemployed householders, and fewer minority heads of household. It is important to note that many of these variables are correlated. Thus only a few coefficients from the probit model in chapter nine turn out to significantly predict a response.

Table 10.2: Sample Means for Survey Respondents and Non-Respondents

	Did not Respond	Responded	Difference in Means	p-value
Parcel-level housing characteristics				
Lot size (acres)	0.587	0.788	-0.201	6.84e-10
House size (1000 sq ft)	1.800	1.992	-0.192	2.91e-09
Structure Quality				
Low	0.455	0.293	0.162	3.66e-23
Good	0.532	0.693	-0.161	9.04e-23
Very good	0.0128	0.0138	-0.00103	0.782
Year Structure Built				
Before 1950	0.260	0.253	0.00649	0.654
1950-1975	0.400	0.380	0.0204	0.205
1975-2000	0.260	0.274	-0.0141	0.330
2000-present	0.0799	0.0927	-0.0128	0.155
Surrounding land use/land cover				
Proportion forest within 1 mile of household	0.235	0.285	-0.0495	1.05e-15
Proportion agricultural within 1 mile of household	0.0725	0.0963	-0.0238	4.08e-7
Proportion highly developed within 1 mile of household	0.230	0.184	0.0453	1.15e-14
Distance to public land (miles)	0.304	0.330	-0.0260	0.0312
Distance to stream (miles)	0.232	0.228	0.00358	0.500
Census tract-level demographics				
Head of household has bachelors proportion	0.417	0.486	-0.0687	8.38e-24
Median household income ($1000)	79.54	88.82	-9.283	2.36e-14
Not worked in past year proportion	0.194	0.181	0.0130	7.28e-09
Head of household racial minority proportion	0.340	0.240	0.100	1.36e-21
Age of head of household	53.30	53.88	-0.577	7.76e-5
Household size	2.533	2.528	0.00526	0.515
Observations	9,937	1,014		

We can only make direct comparisons of household characteristics between respondents and non-respondents as we do in table 10.2 when data are available for both groups. We also included many supplementary questions in the survey itself. Table 10.3 provides percentages of the various responses of survey respondents to certain demographic questions. Interestingly, a large portion of respondents to the survey are in the 50 to 70 age range. Also, males were more likely to respond to the survey than females. Of all respondents, 74% are white and 12% are African American. Respondents are also very likely to be in higher income brackets. A large percentage of respondents live in households with a total income above $150,000. Finally, respondents tend to be highly educated. About 70% of respondents have at least a bachelor's degree.

Table 10.3: Demographic Characteristics of Survey Respondents

Demographic Category	Respondents (%)	**Demographic Category**	Respondents (%)
Age Group		*Income*	
< 30	1.2	<25K	1.9
30-39	10.7	25-49K	7.9
40-49	16.3	50-74K	11.4
50-59	27.3	75-99K	11.1
60-69	26.9	100-124K	13.5
>70	14.6	125-149K	8.6
Prefer not to say	3.0	>150K	21.6
Total	100	Prefer not to Say	23.9
Gender		Total	100
Female	41.5	*Recent Restoration*	
Male	54.8	Yes	16.7
Prefer not to say	3.7	No	38.0
Total	100	Not Sure	45.3
Race		Total	100
American Indian	0.3	*Education Level*	
Asian	2.2	No HS	0.3
African American	11.7	High School	14.5
Hispanic	0.6	Technical School	5.0
Mixed Race	1.8	2 year degree	10.1
White	73.6	Bachelors	32.2
Other	1.7	Advanced Degree	38.0
Prefer not to say	8.1	Total	100
Total	100.00		

The next two tables summarize the responses of survey respondents to self-reported behavioral and attitudinal questions, respectively. Table 10.4 shows how frequently respondents perform several different outdoor recreation activities. We find that 21.6% of respondents walk, run or bike to a public park at least once per week. Similarly, 14.28% of respondents drive to a public park at least once a week. In contrast, the average respondent visits the Chesapeake Bay less frequently. In fact, many respondents never visit the Chesapeake Bay at all for recreation. This is likely because only a small proportion of respondents live in very close proximity to the Bay. We cannot compare these behavioral characteristics with the entire sample population as we did with the characteristics in table 10.2. However, the results in table 10.4 suggest that the survey did not only attract outdoor recreationalists. To some extent, this solidifies the finding in chapter nine that distance decay in WTP seems to be due to non-use factors. Table 10.5 summarizes the responses of survey respondents to questions that asked about their priorities towards various regional water quality goals. We find that each of the priorities we asked about are "very important" to most respondents. Respondents are most likely to find improvements in infrastructure to be a "very important" priority and are least likely to find erosion control to be a "very important" priority. People were most likely to find mosquito control to be "of little importance" or "not important at all".

Table 10.4: Summary of Behavior Characteristics of Survey Respondents

	Never (%)	1-2 times per year (%)	3-12 times per year (%)	1-3 times per month (%)	1-2 times per week (%)	Nearly every day (%)	No Response (%)
I walk, run or bike to a public park in my neighborhood	39.21	10.29	15.31	12.51	12.91	8.69	1.07
I drive to a public park in my neighborhood or an adjacent neighborhood	19.58	19.63	27.25	18.46	11.06	3.22	0.80
I visit regional or state parks (e.g., Gunpowder, Patapsco State Park)	17.18	35.14	29.57	10.61	5.39	1.60	0.50
I visit the Chesapeake Bay for water-related activities (e.g., boating, fishing, swimming, kayaking)	38.54	34.82	17.46	4.50	3.00	1.30	0.40
I visit the Chesapeake Bay for waterfront recreation activities (e.g., picnicking, birdwatching, walking, biking)	34.22	40.78	17.61	3.92	2.00	1.37	0.10

Table 10.5: Summary of Priorities of Survey Respondents

	Not Important At all (%)	Of Little importance (%)	Somewhat Important (%)	Important (%)	Very Important (%)	Not Sure (%)
Reduce water pollution going into the Chesapeake Bay	0.30	0.60	3.42	18.11	76.87	0.70
Reduce water pollution going into the Baltimore Harbor	0.40	0.80	3.72	16.81	77.57	0.70
Improve wildlife habitat in the areas near streams	0.50	1.55	6.72	22.40	67.63	1.20
Improve quality of drinking water supply in the Baltimore region	0.40	1.10	4.90	14.86	77.25	1.50
Reduce sewer pipe leaks and infrastructure damage to roads, bridges and paths	0.10	0.30	2.35	13.96	82.29	1.00
Reduce erosion along the stream banks	0.50	1.20	7.42	26.27	63.54	1.07
Reduce mosquito populations that live near streams	1.00	2.60	8.92	18.46	66.66	2.37
Remove trash left in and along streams	0.30	0.50	2.90	18.96	75.97	1.37

10.2. Survey Instrument Example

Thank you for participating in this survey! The University of Maryland is conducting this survey to understand opinions about stream restoration and to inform local agencies and citizen groups about what design features of stream restoration are most desirable. Please answer all of the questions you can, but you are not required to do so. Please read the background information and then complete the survey. The survey should take about 15 minutes.

Why are we concerned about the water quality of streams in our area?

Urban and suburban development in the Baltimore area has been extensive over the past century. Although the roads, houses, driveways and other landscape changes necessary for development bring many benefits to citizens, they also have some unintended impacts. The following photographs and captions explain the impacts on water quality in local streams.

Impervious surfaces in urban areas include roads, rooftops, parking lots and driveways. These hard surfaces do not absorb rainwater during storms.

Impervious surface from urban and suburban development may increase streamflow and flooding, particularly during and after storms.

Increased streamflow and flooding can lead to severe erosion of stream banks.

Eroded stream banks can make public parks or backyards in residential areas less attractive.

Streambank erosion can also impact public infrastructure like this biking and walking path.


Streambank erosion can cause infrastructure damage to sewer pipes, leading to untreated sewage leaking into local streams.


Increased water pollution going into local streams, lakes and the Chesapeake Bay leads to growth in algae, which can lead to conditions inhospitable for fish and other aquatic wildlife.


Increases in algae can reduce oxygen in water bodies, leading to “dead zones” where fish and other aquatic organisms struggle to survive.

Section A. Stream Restoration

A1. Before taking this survey, how familiar were you with the idea of stream restoration projects?

[ ] Very familiar
[ ] Moderately familiar
[ ] Somewhat familiar
[ ] Not familiar

A2. Before taking this survey, how familiar were you with the issue of water pollution in local streams and the Chesapeake Bay watershed?

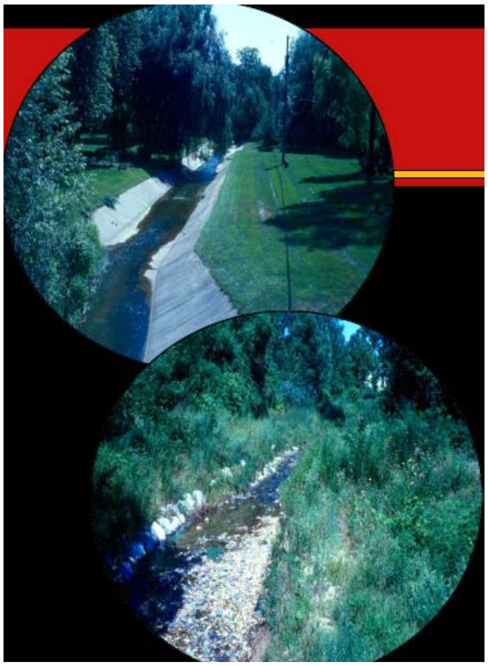
[ ] Very familiar
[ ] Moderately familiar
[ ] Somewhat familiar
[ ] Not familiar

A3. Has there recently been a stream restoration project completed within walking distance of your home?

[ ] Yes
[ ] No
[ ] Not Sure

What are stream restorations and how can they help with water quality and infrastructure protection?

Stream restoration projects alter the structure of urban streams, their banks and surrounding areas in order to mitigate these negative impacts from urban and suburban development. Stream restoration absorbs nutrients and stabilizes stream banks, which leads to less erosion. This in turn improves water quality in the Chesapeake Bay and reduces potential damage to infrastructure, such as sewer pipes, roads and bridges.



This stream restoration project included replacement of a concrete-lined stormwater ditch with a natural streambed lined with large stones along the stream. The mowed grass was replaced by a meadow with native grasses and bushes to absorb nutrients and provide wildlife habitat.

How does the government decide whether to restore a stream?

The State of Maryland, including Baltimore City and Baltimore County, are legally required to reduce water pollution entering waterways and the Chesapeake Bay. Local governments must come up with strategies for reducing water pollution and its damaging effects on the Bay, and stream restoration is one strategy that has been strongly considered as a local approach. Stream restorations are also built to reduce the risk of damage to sewers and other public infrastructure.

Section B. Your Neighborhood

B1. How long have you lived in your neighborhood?

[ ] less than a year
[ ] 1-3 years
[ ] 3-5 years
[ ] 5-10 years
[ ] more than 10 years

B2. Do you rent or own the residence where you currently live?

[ ] rent
[ ] own

Section C. Your Recreational Activities

C1. For each statement below, please select the response that most accurately represents the frequency of your recreational activities in the past year.

	Never	1-2 times per year	3-12 times per year	1-3 times per month	1-2 times per week	Nearly every day
I walk, run or bike to a public park in my neighborhood	1	2	3	4	5	6
I drive to a public park in my neighborhood or an adjacent neighborhood	1	2	3	4	5	6
I visit regional or state parks (e.g., Gunpowder, Patapsco State Park)	1	2	3	4	5	6
I visit the Chesapeake Bay for water-related activities (e.g., boating, fishing, swimming, kayaking)	1	2	3	4	5	6
I visit the Chesapeake Bay for waterfront recreation activities (e.g., picnicking, birdwatching, walking, biking)	1	2	3	4	5	6

C2. How important is it that the county or city achieve each of the following goals in your area?

	Not Important At all	Of Little importance	Somewhat Important	Important	Very Important	Not Sure
Reduce water pollution going into the Chesapeake Bay	1	2	3	4	5	N/A
Reduce water pollution going into the Baltimore Harbor	1	2	3	4	5	N/A
Improve wildlife habitat in the areas near streams	1	2	3	4	5	N/A
Improve quality of drinking water supply in the Baltimore region	1	2	3	4	5	N/A
Reduce sewer pipe leaks and infrastructure damage to roads, bridges and paths	1	2	3	4	5	N/A
Reduce erosion along the stream banks	1	2	3	4	5	N/A
Reduce mosquito populations that live near streams	1	2	3	4	5	N/A
Remove trash left in and along streams	1	2	3	4	5	N/A

Section D. Choosing Options for Proposed Stream Restoration Projects

The pictures below provide background information about the design features of stream restoration and how each feature impacts degraded streams. Please look carefully at each feature because the next four questions will ask you to choose between stream restoration projects with different combinations of these features.

Access to Stream Restoration

Publicly Accessible

Streams often pass through public land such as parks, schools or along roads. When stream restorations are located on public land, anyone can visit them.

Not Publicly Accessible

Streams often pass through private property and are generally not accessible by the public. When stream restorations are placed on private property, only the property owner has access to the direct benefits of stream restoration but some indirect benefits to water quality may also accrue downstream to the Bay.

Proximity to Stream Restoration

Streams are widely distributed throughout the Baltimore region. The location of a restoration project may be proposed for a stream at varying distances from your home. For this survey, three categories are used to describe the distance of the stream restoration from your home:

- stream in **walking distance from your home (within 1 miles)**,
- stream in **driving distance from your home (1 to 5 miles away)** and
- stream in **driving distance from your home (more than 5 miles away)**.

Near-Stream Vegetation

Meadow

A stream restoration project may include creation of a meadow planted with native grasses and shrubs. This can help to provide sunlight and space for walking around or having picnics. Meadows are effective at reducing water pollution and soil erosion.

Forested

A stream restoration project may include trees on site (either planting new trees or retaining old mature trees). Trees can help to provide shade and create a quieter stream location. Trees are effective at reducing water pollution and soil erosion.

Appearance of Stream

No Changes Made

If left unprotected, the stream bank will continue to be eroded and further degraded. This can lead to potential infrastructure damage to sewer pipes and leakage of untreated sewage into streams.

Boulders and Stones

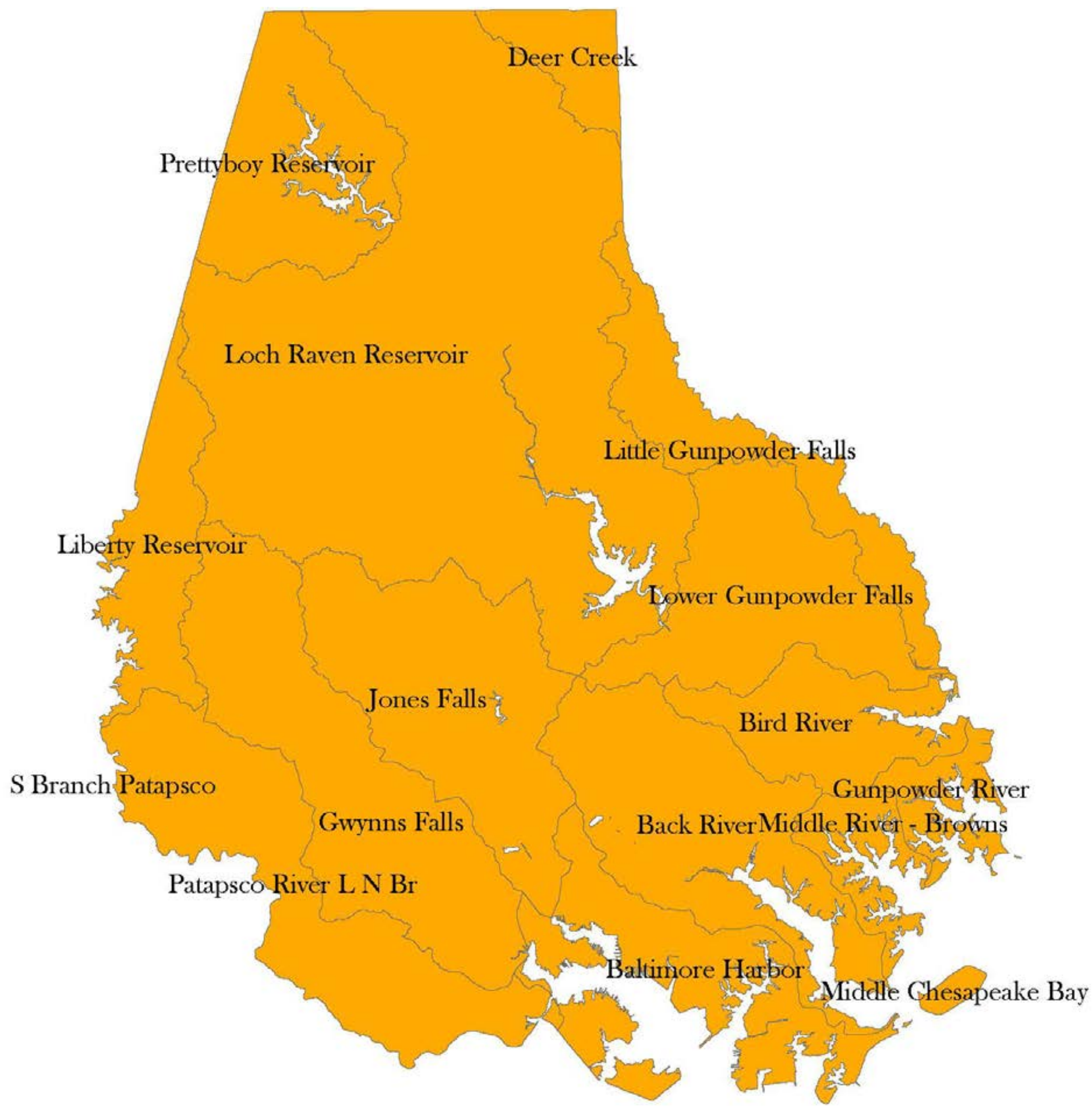
Stream restoration projects sometimes feature placement of boulders and stones along the stream banks to reduce stream bank erosion and protect sewer lines and other infrastructure along streams.

Wetland Added

Wetlands may be created to include low grassy areas that improve wildlife habitat and reduce nutrient pollution and erosion. However, the wet ground may make the site more difficult for walking close to the stream.

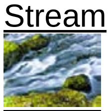
Stream & Bay Pollution Reduced

Stream restorations help to achieve water pollution reductions that are legally mandated for local streams and the Chesapeake Bay. The map below shows the 16 separate water zones for Baltimore County and City. Each stream restoration project will meet some **percentage of the yearly water pollution reduction goal** in *one* of these water zones.

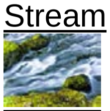


D1. Restoration projects A and B are two possible options to restore a **1000 foot** section of a degraded stream (about the length of 3 football fields). The "current situation" means no restoration project will be done at this stream location and no costs are expended. The stream is **publicly accessible** (at a park, school, or along the road) and **within walking distance** of your home (within a mile). Which of the three options below would you vote for?

Please consider this as if it were a real world example. This is not currently related to any ballot issue that you will vote for in any election, but it could be informative for actual decisions on restoration projects in your area.

	Current Situation (no restoration)	Restoration Project A	Restoration Project B
Location of Stream 	This stream is **publicly accessible** (At a park, school, or along the road) And it is **within walking distance** of your home (within a mile)		
Near-Stream Vegetation 	Forest and Meadow Mixed Land left as it is	Forested Trees planted	Meadow Removes some trees
Appearance of Stream 	No Changes Made Erosion and infrastructure damage will worsen	Boulders and Stones Added Protects infrastructure, reduces erosion	Wetland Added Provides wildlife habitat, reduces erosion
Stream & Bay Pollution Reduced 	Meets 0% of goal for water zone For yearly pollution reduction	Meets 50% of goal for water zone For yearly pollution reduction	Meets 10% of goal for water zone For yearly pollution reduction
One-Time Cost to Your Household 	$0	$60	$10

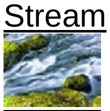
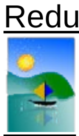
D2. Now assume a similar stream at a different location is proposed for a stream restoration. The stream is **not publicly accessible** (on someone's private property) and **driving distance** from your home (1 to 5 miles away). Restoration projects C and D are two possible options to restore a **1000 foot** section of the degraded stream (about the length of 3 football fields). The "current situation" means no restoration project will be done at this location and no cost expended. Which of the three options below would you vote for?

	Current Situation (no restoration)	Restoration Project C	Restoration Project D
Location of Stream 	This stream is **not publicly accessible** (on someone's private property) And it is **driving distance** from your home (1 to 5 miles away)		
Near-Stream Vegetation 	Forest and Meadow Mixed Land left as it is	Forested Trees planted	Forest and Meadow Mixed Land left as it is
Appearance of Stream 	No Changes Made Erosion and infrastructure damage will worsen	Boulders and Stones Added Protects infrastructure, reduces erosion	No Changes Made Erosion and infrastructure damage will worsen
Stream & Bay Pollution Reduced 	Meets 0% of goal for water zone For yearly pollution reduction	Meets 10% of goal for water zone For yearly pollution reduction	Meets 25% of goal for water zone For yearly pollution reduction
One-Time Cost to Your Household 	$0	$60	$100

D3. Now assume a similar stream at a different location is proposed for a stream restoration. The stream is **not publicly accessible** (on someone's private property) and **within walking distance** of your home (within a mile). Restoration projects E and F are two possible options to restore a **1000 foot** section of the degraded stream (about the length of 3 football fields). The "current situation" means no restoration project will be done at this location and no cost expended. Which of the three options below would you vote for?

	Current Situation (no restoration)	Restoration Project E	Restoration Project F
Location of Stream 	This stream is **not publicly accessible** (on someone's private property) And it is **within walking distance** of your home (within a mile)		
Near-Stream Vegetation 	Forest and Meadow Mixed Land left as it is	Forest and Meadow Mixed Land left as it is	Forested Trees planted
Appearance of Stream 	No Changes Made Erosion and infrastructure damage will worsen	Boulders and Stones Added Protects infrastructure, reduces erosion	Wetland Added Provides wildlife habitat, reduces erosion
Stream & Bay Pollution Reduced 	Meets 0% of goal for water zone For yearly pollution reduction	Meets 10% of goal for water zone For yearly pollution reduction	Meets 50% of goal for water zone For yearly pollution reduction
One-Time Cost to Your Household $	$0	$10	$60

D4. Now assume a similar stream at a different location is proposed for a stream restoration. The stream is **publicly accessible** (at a park, school, or along the road) and **driving distance** from your home (1 to 5 miles away). Restoration projects G and H are two possible options to restore a **1000 foot** section of the degraded stream (about the length of 3 football fields). The "current situation" means no restoration project will be done at this location and no cost expended. Which of the three options below would you vote for?

	Current Situation (no restoration)	Restoration Project G	Restoration Project H
Location of Stream 	This stream is **publicly accessible** (At a park, school, or along the road) And it is **driving distance** from your home (1 to 5 miles away)		
Near-Stream Vegetation 	Forest and Meadow Mixed Land left as it is	Forest and Meadow Mixed Land left as it is	Meadow Removes some trees
Appearance of Stream 	No Changes Made Erosion and infrastructure damage will worsen	No Changes Made Erosion and infrastructure damage will worsen	Wetland Added Provides wildlife habitat, reduces erosion
Stream & Bay Pollution Reduced 	Meets 0% of goal for water zone For yearly pollution reduction	Meets 20% of goal for water zone For yearly pollution reduction	Meets 30% of goal for water zone For yearly pollution reduction
One-Time Cost to Your Household 	$0	$60	$75

Section E. Attitudes and Knowledge

E1. Please rate each of the following statements as it pertains to you.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Protecting the Chesapeake Bay is important to me personally	1	2	3	4	5
Reducing environmental degradation and improving the appearance of streams, paths and public green spaces in my neighborhood is important to me	1	2	3	4	5

Section F. Demographic Information

F1. What is your age?

[ ] Less than 30
[ ] 30 to 39
[ ] 40 to 49
[ ] 50 to 59
[ ] 60 to 69
[ ] 70 or over
[ ] Prefer not to say

F2. What is your gender?

[ ] Female
[ ] Male
[ ] Prefer Not to Say

F3. What is your racial or ethnic group? Check all boxes that apply.

[ ] White
[ ] Black or African American
[ ] Hispanic
[ ] American Indian or Alaskan Native
[ ] Asian
[ ] Mixed Race
[ ] Other
[ ] Prefer Not to Say

F4. Please indicate the highest level of education you have completed. Please select one answer.

[ ] No high school degree
[ ] High school degree or GED
[ ] Technical or trade school graduate
[ ] Two-year college degree
[ ] Four-year college degree (BA, BS)
[ ] Advanced degree (MA, MS, PhD, JD, MBA, etc.)

F5. How many people (including yourself) live in your household?

☐

F6. How many children (0-18 years old) are living in your household at least 50% of the time?

[ ]

F7. Please indicate your household's total gross annual income. Please include all sources of income.

[ ] less than $25,000
[ ] $25,000 to $49,999
[ ] $50,000 to $74,999
[ ] $75,000 to $99,999
[ ] $100,000 to $124,999
[ ] $125,000 to $149,999
[ ] $150,000 or more
[ ] Prefer not to say

F8. Have you ever belonged to or donated to any environmental group or watershed association?
[ ] Yes
[ ] No

Thank you for participating in this survey.
You are now eligible to participate in a raffle to potentially win an Amazon gift card.
If you would like to be entered into the raffle, please enter your name and mailing address below.
Full name:
____

Full mailing address:____

Please check the box below if you would like to opt out of the raffle.

☐ Do NOT include me in the raffle

If you would like to receive a copy of the final report this study, please enter your email address below:

This study has been approved by the Institutional Review Board at the University of Maryland. Should you have any concerns about the study, feel free to contact Andrew Rosenberg at arosenb5@umd.edu or (410) 302-2013. Please be assured that all information you have provided will remain confidential.
If you have any final comments about the survey, please enter them below:

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