An Analysis of the Impact of Tenure on Groundwater Use and Attitudes Concerning Groundwater Conservation in Colorado's Republican River Basin

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ABSTRACT

Groundwater pumping from an aquifer that exceeds the recharge rate results in decreases in future groundwater availability and well capacity. Economic research on groundwater pumping has generally assumed that groundwater is being managed myopically (Koundouri, 2004), although research from Pfieffer and Lin (2013) suggests that producers make dynamic groundwater use decisions. Other empirical analysis has lead researchers to conclude there is little difference between myopic decision making and dynamic groundwater extraction strategies (Savage, 2011). Our research within the Republican River Basin of Colorado contributes to the literature by analyzing the impacts of land tenure on the extent to which tenants and owners make dynamically informed decisions. We find no evidence of heterogeneity in groundwater use as a result of land tenure, suggesting that groundwater decisions are being made myopically. Our research also uses data from a recently conducted survey within the region to examine the impact that tenure has in determining concern regarding groundwater availability, and support for policies within the region that would seek to conserve groundwater. Estimating multiple probit regressions, we find that tenant operators are less likely to be concerned about the long-term availability of groundwater, and that they are less likely to support groundwater management districts working to develop strategies that would seek to promote groundwater conservation. We do not find that tenure has an impact on support for specific policy mechanisms, but rather that well capacity is pivotal in driving support for policies.

1. INTRODUCTION

The Ogallala aquifer spans across parts of eight states (Colorado, Kansas, Oklahoma, Texas, Nebraska, South Dakota, New Mexico, and Wyoming) and underlies 111.8 million acres. Colorado has approximately 9.54 million acres over the Ogallala aquifer, an area larger than the state of Maryland, all on the eastern plains (USDA, 2016). Before the 1950s, there was minimal groundwater irrigation in the Ogallala. Between 1950, when people began withdrawals from the aquifer for irrigated agriculture, and 2013 overall water levels in the Ogallala have decreased by approximately 266.7 million acre-feet, which represents a decline of approximately eight percent (McGuire, 2014). Colorado has seen a decrease in water storage of 18.8 million acre feet. The vast majority of the withdrawals from the Ogallala are for irrigation, with some estimates as high as 94% of Ogallala use (MIT, 2012). Nearly a fifth of U.S. produced corn, cotton, and wheat come from land that is irrigated by the Ogallala aquifer and nearly 30 percent of all groundwater pumped in the United States is being used in the region. This paper will focus on the difference in behavior and policy preference amongst tenants and owners in the agricultural sector within Colorado. The differences, or lack thereof, in behavior will inform our support for whether groundwater users are behaving myopically, dynamically, or strategically, while differences in policy preferences will provide information on the political feasibility of a groundwater management policy being implemented.

Throughout the paper, we use the terms myopic, dynamic, and strategic decision makers. We define a myopic decision maker as an individual who is maximizing profits in the current time period, without regard for the impact their production decisions have on their own groundwater availability in future time periods, and without regard for the spatial impacts that their pumping has on neighboring wells. We define dynamic decision makers as individuals who consider the impact that their decision-making has on their ability to use the resource in the future, however they are not considering the impact that other individuals have on the stock of the aquifer. A strategic decision maker considers the future impact of their decisions in the current time period, as well as the impact that other neighboring decisions makers will have on their ability to pump water in the future. While it is unlikely the optimal dynamic extraction plan is the same as the myopic pumping amount, it is possible that the strategically optimal amount of water for an individual is not different from the amount extracted by the myopic decision maker. This is possible if the strategic decision maker concludes that pumping from neighboring wells would decrease future groundwater availability regardless of the amount of water that they use.

Economic intuition suggests that behavioral differences as well as heterogeneity in conservation attitudes may exist between farmers who own land, and farmers who are renting land. Assuming that both owners and tenants are exhibiting profit-maximizing behavior, they would be making decisions regarding the aquifer, which is an input to their production, over different time periods. The owner's profit maximization function is over an extended period of time and is tied to the productivity of the land and the future value that can be gained from the stock of the resource. A tenant has a contract for a designated period of time, at which point the remaining stock of the resource is no longer of value to the producer. Thus, we would expect renters to be more likely to make profit-maximizing decisions with no regard for the stock of the groundwater input after the expiration of their contract. Within the region, many operators both own and rent land. We anticipate their behavior will vary amongst wells they own, and wells that they rent. Aquifer health varies spatially, thus an owner would have the incentive to manage their own wells dynamically, however there is less of an incentive for them to consider the future economic viability of another individual's well that they are managing.

An owner may also have a non-market bequest value regarding the aquifer if they would like their family to be able to continue to use the aquifer as a means of production when they retire. The tenant would be less likely to be concerned about the ability of their family to use the aquifer, as it is not their property right to pass on. Given the economic dependence the region has on groundwater pumping, it is possible that owners may be inclined to have a non-market valuation in the wellbeing of the community that some tenants do not have, however, given the large number of tenants living within the region, heterogeneity in pumping and conservation support between different tenure classes remains an open question.

If tenants are pumping more than owners, it supports the hypothesis that they are making decisions on a different time scale than owners. If there is not empirical evidence that tenants and owners are behaving differently then it would support many economists current view that groundwater is being managed myopically (Koundouri, 2004; Peterson, Marsh, & Williams, 2003). In other words, it would suggest that not only are the tenants pumping at a rate that is not dynamically optimal, but that owners of the land are making these decisions myopically as well, meaning they are not considering the future availability of the resource when they are making decisions. The results could be used to determine if a certain group is more prone to overuse the common resource. If producers are withdrawing from the aquifer at a greater rate than the socially optimal level, the benefits the individual receives from pumping are outweighed by the external social cost of pumping water. Furthermore, even if there are not tangible effects of the aquifer depletion short term, long term depletion impacts individuals' abilities to extract water from the aquifer in the future.

There is currently no explicit groundwater management policy in place in the Republican River Basin in Colorado that internalizes the social cost of pumping. This paper analyzes the concern about groundwater availability, general support for groundwater management districts working to develop conservation policy, and the support for three specific policies that would decrease groundwater pumping throughout the region by either 10 or 25 percent, dependent upon the level at which they were implemented. While synthesizing the previous research on the adoption of agriculture practices intended to increase conservation, Knowler and Bradshaw (2006) find that the determinants of conservation support and adoption vary spatially and need to be analyzed at the local level. We are able to contribute to the literature, by analyzing data from a recent survey in order to find determinants of groundwater conservation policy support within the Republican River Basin of Colorado.

2. LITERATURE REVIEW

Previous research in the field of economics, along with other academic disciplines, has informed our research. The following section details the research, methods, and findings of previous authors, and provides an explanation of how our research contributes to the existing literature. The literature review is broken into three general categories, with the first section discussing the common property attributes of an aquifer, the second discussing the existing research that has analyzed whether groundwater pumping decisions are made myopically or dynamically, and the third section which synthesizes the existing literature on the factors influencing conservation support, with a focus on articles that have examined the influence land tenure has on either conservation support or adoption or conservation practices.

Common Property Attributes of an Aquifer

Our research examines whether the tragedy of the commons problem that is seen in aquifer extraction, is exacerbated by differences in land tenure. Peterson, Marsh, and Williams (2003) explain why it is likely an aquifer will be extracted beyond what is optimal for society, or the economically efficient level. Due to the common property attributes of an aquifer, the optimal pumping level for each individual is higher than the socially optimal rate, which suggests that the aquifer will be used at a rate that is economically inefficient. Each user holds a property right to pump water, while no user holds a property right to the water within the aquifer. Thus, when a user extracts water they are paying the cost of pumping, but not paying a price that is indicative of the value of water. Private costs of pumping are less than the social costs of a unit of water, thus excessive pumping occurs. The authors go on to list three external costs of pumping that are realized by society, but not necessarily fully realized by the individual producer. There is the stock cost, which indicates that future users will not be able to use the water that was pumped by the individual today. Then there is the depletion cost, which is the increased cost in irrigation as well capacity decreases and higher effort levels are required in order to withdraw water. Then, there is the risk cost, which indicates that as the water is pumped today it can no longer be used as a water bank when drought occurs. Aquifers are viewed as a tool for risk mitigation, when the aquifer is overdrawn, it has a decreased value as a risk management tool. These external costs are distributed amongst society, while the producer solely realizes the benefits of the water they extract. Thus, it is not surprising that a producer would withdraw at a rate that is not socially optimal when the marginal cost of each unit of water withdrawn to society is far different than the marginal cost the producer is facing

Decision-Making Timeline of Producers

There is a debate regarding whether groundwater pumping decisions are made myopically or dynamically. To further investigate this question, we analyze the difference in groundwater extraction between wells operated by owners and wells operated by tenants, two groups that would theoretically be operating under different economic timelines. Pfieffer and Lin (2013) analyzed the impact of property rights on groundwater management in a portion of the Ogallala aquifer that overlies Kansas. A hydro-economic model was developed to test multiple decision-making scenarios, in which farmers are making decisions both myopically and dynamically to compare the optimal groundwater extraction strategies given different time periods. The myopic model depicted farmers maximizing profits over a year, while the dynamic model depicted farmers maximizing profit with respect to the current year, while also considering future value that can be gained using the resource. A reduced form estimation equation tested to see if decisions were being made myopically without considering the user cost, which is the decrease in the value of the land from the use of the aquifer. The rejection of this hypothesis would suggest that a model that considers the future value of groundwater not harvested in the current time period would be a more appropriate way to model groundwater pumping decisions. In Pfieffer and Lin's conceptual model, the author theorized that the doctrine of prior appropriation would encourage groundwater users to pump their maximum allowable amount each year, however, the author found evidence of strategic withdrawals of groundwater. Variables of significance that suggest that decisions are being made dynamically include the stock and recharge rate of the aquifer where the decision maker is located, fluctuations of the prices of crops, the expected future fluctuations of the prices in crops, and neighbors' groundwater pumping. The authors argued that significance in the stock and recharge rate indicated that farmers were factoring in the stock of the future resource while making decisions. They also suggested that an expected decrease in crop prices would lead to increased pumping in the current time period, given the decrease in the potential future profits due to lower crop prices. Given these findings, it is possible there may be variation in the pumping decisions of those who make dynamically optimal decisions and those who make decisions on a yearly, or at least a significantly shorter timeline.

Savage and Brozovíc (2011) developed a groundwater model that analyzed pumping decisions in the Nebraska portion of the Republican River Basin, accounting for heterogeneity in space and in neighbors' pumping decisions. Within their behavioral model, the authors explained that a myopic user would ignore the externality that pumping imposes on neighboring wells, and extract water to the point at which the marginal value of water is equal to zero. Using estimates from Palazzo (2009), the authors construct an estimate of myopic pumping amounts, which is then used in their econometric model. The authors found that they were unable to reject their hypothesis that farmers are extracting groundwater myopically. They stated that their research is consistent with previous work by Karp (1992), as well as research by Rubio and Casino (2003). Both papers theoretically suggest that there will be a negligible difference between myopic decision-making and strategic extraction for common pool resources.

Our research looks to contribute and potentially add an explanation to the existing literature on groundwater extraction, for which there is currently evidence that suggests that strategic pumping is present, as well as existing research that suggests that there would be not be a noticeable difference between myopic and strategic pumping within the Ogallala aquifer.

Determinants of Conservation Support and Adoption

The remaining articles contribute to the literature concerning what influences support for conservation related policies and practices in agriculture. As previously mentioned, Knowler and Bradshaw (2006) synthesized the previous literature, and reviewed 23 articles that analyzed the determinants of adopting conservation oriented agricultural practices. The location of the analyses that looked at technology adoption varied across eight different countries, with the majority being located within the US. The synthesis excludes research that analyzes theoretical adoption, and only looks conservation technologies that have been adopted. All of the technologies were intended to minimize the inputs of production in the agricultural process. Eleven of the studies analyzed by the authors included land tenure as a variable that would indicate whether a farmer was more likely to adopt conservation agriculture practices such as soil conservation and erosion control. The authors stated that while theory suggested owners would be more prone to implement conservation agriculture practices than those who lease, only two of the eleven studies supported this hypothesis. Two studies found evidence that refuted the notion that farmers who own their land would be more likely to engage in conservation agriculture practices, and the remaining studies found no significant relationship between land tenure and adoption of conservation agriculture. The inconsistency of findings from the multitude of studies analyzed lead the authors to conclude that variables that impact conservation agriculture need to be determined on a local basis and that few variables apply universally to determining the adoption of conservation agricultural practices.

Early work by Carlson et al. (1977) analyzed interview data of absentee landowners and farmers in the Palouse region of Washington and Idaho and found heterogeneity in the perceptions of soil conservation between absentee landowners and farmers. The authors found differences in the demographics of absentee owners, finding they were older, more educated, and that a higher percentage of absentee owners were female. A third of absentee owners had very little knowledge of the operation. Survey data indicated that landlords were slightly less worried about erosion control as compared to farmers. However, it is interesting to note that despite this difference, landlords were found to have higher levels of concern than the farmers anticipated. Thus, farmers were found to have a misconception of the owners' concern regarding conservation. Owners were found to be more worried about the cost of erosion control than farmers were, however, absentee owners were more likely to support outright regulation than farmers in the region. Farmers felt regulation limited their freedom to make decisions, and would be less effective than long-term incentive programs. It is possible that we find that farmers are more resistant to specific policy mechanisms as well, as it would directly impact how they make decisions, while absentee owners may be aware of the policy in their daily actions.

We analyze both the behavior and attitudes of owners and tenants. Our research assumes that ceteris paribus, less groundwater use by owner operators as compared to tenant operators can be a result of lower levels of effort put forth by tenants on conservation. Research by Lynne et al (1988) made the claim that profit-maximizing models were insufficient in fully capturing the decision-making behind conservation adoption of farmers, because not all farmers were equally motivated by income. They developed a behavioral model, which incorporated farmers' attitudes, values, beliefs and intentions as causal factors influencing conservation decisions. Soil management decisions captured through a survey of 103 farmers in Florida were used to test the aforementioned model. An extension of the tobit model was used to test the causal factors leading to the adoption of conservation measures. Rather than a binary variable which indicates whether conservation action has been taken or not, they attempt to measure conservation implementation on a scale, in which different levels of effort are put forth given the different conservation measures that are implemented. The authors then assumed effort to be a good, albeit not perfect, proxy for expenditures. A dummy variable was included to measure the effect tenure had on soil conservation. The findings were consistent with their hypothesis, that renters would put forth less conservation effort than owner operators. The coefficient that compared renters to those who both owned and rented was positive and significant, and the coefficient that compared those who rented to those who only operated their own land was positive and almost significant at a

10% level. The sign implies that ceteris paribus, owners are likely to expend more effort on conservation than renters, which we would consider more dynamic behavior as they are considering future time periods, while renters are behaving more myopically as they are less willing to conserve now for future benefits.

Soule et al. (2000) analyzed the resource stewardship of owner and tenant operators in a study of 941 corn farmers across 16 states, attempting to identify variables that would lead to the adoption of conservation practices. The authors differentiated between lease types, looking at both cash renters and share renters. They found that conservation adoption varied depending upon both the timeline that the benefits of conservation action would be realized, as well as the type of lease the farmer was operating under. Cash renters were less likely to adopt conservation tillage practices than both share renters, and owner operators. They also found that both cash and share renters were less likely to adopt medium term conservation practices compared to owner operators. Using a logit adoption model, with the different conservation variables as the dependent variables, the authors analyzed the impact that different explanatory variables such as age, education and regional dummy variables had on different tenure classes. The authors found that in addition to tenure class playing a role in impacting the probability of adopting different conservation practices, the impact of explanatory variables varied across tenure class. Our research analyzes whether there is heterogeneity found between conservation attitudes in owner operators and tenant operators, and if so, whether this translates to conservation minded water use, or if water use is an area within farm management where decisions tend to be made similarly regardless of tenure status.

Research on the impact of land tenure on environmental stewardship is not limited to the field of economics. Research from Cole and Johnson (2002) explored the impact of land tenure on environmental responsibility and found no difference in the management of land due to land tenure. They found that social pressure and norms influenced tenant operators as they would owner operators, and that both groups tend to operate in an environmentally responsible manner. While some of the literature on groundwater management finds that there is little difference between owners and tenants, it has generally been shown that the lack of heterogeneity in pumping stems from myopic decision-making by both the owner and tenant, rather than both owner and tenant acting in what could be determined as a conservation-minded approach (Koundouri, 2004; Peterson, Marsh, & Williams, 2003).

Peterzelka et al. (2013) provided a synthesis of peer reviewed literature of state and federal policies that address absentee ownership of forests, rangeland, and farmland. They found that absentee owners are more likely to live in urban areas and are generally less likely to be financially dependent upon natural resources of the land they own. They are also more likely to own land for non-production reasons, however, this may be less likely to apply in eastern Colorado. Our research looks to contribute and potentially provide some clarity to the existing literature, as there are a number of articles that find that absentee owners have differing levels of conservation motivation. Along with other implications for future research, one of their recommendations is to determine the conservation impacts of absentee owners. Our research provides insight on the impact of absentee owners by examining the farm management decisions made by tenant operators in their absence. Through statistical analysis of groundwater pumping, we examine whether wells that are operated by their owners are being managed systematically differently, or if all wells regardless of tenure are being operated myopically.

Research by Ervin and Ervin (1982) evaluated soil conservation practices amongst producers as a function of economic, institutional, personal, and physical factors. They did not attempt to capture the impact land tenure had on soil conservation attitudes, however they use a farm orientation index developed by Kliebenstein (1980) to determine the motivation behind farming. They also constructed a conservation attitudes index comprised of a farmer's views on soil erosion, water quality, and farmer's view of the government as a mechanism to address conservation issues. The authors did not find that farm orientation or conservation attitudes influenced soil conservation practices. As previously mentioned, we use stated concern from our survey of producers in eastern Colorado to evaluate the influence that physical well characteristics, personal factors, and land tenure have on water extraction.

More recently, Reimer et al. (2012) interviewed Indiana producers to obtain information on their environmental attitudes and subsequent conservation behavior. They concluded that the decisions impacting the adoption of conservation practices are made in an interconnected manner with environmental, financial, and agronomic characteristics affecting conservation adoption. Using data from 32 interviews in central Indiana, the authors found that differences in farming motivation lead to differences in conservation decisions. Those who viewed farming primarily as a business were less likely to make conservation decisions, however farmers who were more aware of and concerned about externalities generated by farming, and farmers who viewed themselves as stewards of the land rather than exclusively business operators, were more likely to take conservation action. Conservation actions, especially within the subset of people who have implemented the most conservation practices, are being motivated by non-monetary factors. The authors also believe that the context for which conservation efforts are potentially implemented are more important than previously realized. Thus, they assert that conservation policy should be implemented at a local level.

3. THEORETICAL MODEL

This section describes the theoretical model of a dynamic and a myopic decision-maker that informs our hypothesis that individuals who are operating their own wells are more likely to be making decisions dynamically, while tenants who are operating another individual's property right will be more likely to make decisions myopically. From these models, we also discuss the intuition behind why we expect tenants to be less concerned about groundwater availability in future time periods, and why we hypothesize that they would be less supportive of policies that promote groundwater conservation throughout the region.

Dynamic Decision Making Model

We assume that producers are profit maximizing, and we have simplified our model so that the amount of water pumped is the only choice variable. In the following models, π_i represents profit from well *i*, *P* represents the price of the crop produced, and Q_i represents the quantity of the crop produced at well *i*. The quantity produced is a function of well capacity, which is represented by variable z_i, the amount of water applied which is a choice variable and represented by w_i, soil characteristics which are represented by s_i, precipitation represented by r_i, and a vector of other variables that are not specified in our theoretical model and are represented as Θ_i. The output price is exogenous to our model, and we assume that initial well capacity is also exogenous. Well capacity influences the quantity produced, however is it also a state variable, which is a function of the amount of water pumped in the previous time periods. The amount of water pumped is a choice variable. The price of energy is represented by c and is exogenous to our model. The variable d_i represents the depth to groundwater at the well. Thus, profit in a given year is represented as

$$\pi_i = P * Q_i(w_i; z_i, s_i, r_i, \Theta_i) - c * d_i * w_i \ . \qquad (1)$$

If it is assumed that the owner operator is a dynamic decision maker that maximizes discounted profits across all future time periods, which are represented by subscript $t = 0,1, \dots T$, then each dynamic operator's objective function and related constraints can be written as:

$$\text{Max}_{w_{it}} \ \sum_{t=0}^{\infty} \rho^t \pi_{it} = \sum_{t=0}^{\infty} \rho^t [P_t * Q_{it}(w_{it}; z_{it}, s_{it}, r_{it}, \Theta_{it}) - c_t * d_{it} * w_{it}] \quad (2)$$

$$\text{s.t.} \qquad z_{it+1} = z_{it} - f\left(\sum_{j=1}^{J} w_{it}\right) \qquad (3)$$

$$d_{it+1} = d_{it} - g\left(\sum_{j=1}^{J} w_{it}\right) \qquad (4)$$

The two constraints in equations three and four demonstrate there is a relationship between the water pumped in the current time period, and the well capacity and depth to groundwater in the following time period. The subscript $j=1,2,\dots,J$ represents well i and other wells close enough in proximity to well i for their pumping to have an impact on future groundwater availability at well i. The functions f and g represent the impact that current pumping in the vicinity of well i has on outcomes in future time periods. In other words, well capacity and depth to groundwater are not only functions of the amount of water that the individual withdraws from their own well, but both state variables are also impacted by the actions of other nearby groundwater users. As more water is withdrawn from the aquifer, well capacity decreases in future time periods. Depth to groundwater increases as pumping increases, thus increasing the energy costs of pumping over time. The Lagrangian and first order conditions can be written as

$$\mathcal{L} = \sum_{t=0}^{\infty} \rho^t \Big[\; P_t * Q_{it}(w_{it}; z_{it}, s_{it}, r_{it}, \Theta_{it}) - c_t * d_{it} * w_{it} + \lambda_i \Big(z_{it+1} - z_{it} + f\big(\textstyle\sum_{j=1}^{J} w_{it}\big)\Big) + \eta_i \Big(d_{it+1} - d_{it} - f\big(\textstyle\sum_{j=1}^{J} w_{it}\big)\Big)\Big] \qquad (5)$$

$$\frac{d\mathcal{L}}{dw} = \; P_t * \frac{dQ_{it}(w_{it}; z_{it}, s_{it}, r_{it}\Theta_{it})}{dw_{it}} - c_t * d_{it} + \lambda_i - \eta_i \; \leq 0 \qquad (6)$$

$$\frac{d\mathcal{L}}{d\lambda} = \; z_{it+1} - z_{it} + f\big(\textstyle\sum_{j=1}^{J} w_{it}\big) \geq 0 \qquad (7)$$

$$\frac{d\mathcal{L}}{d\eta} = d_{it+1} - d_{it} - f\big(\textstyle\sum_{j=1}^{J} w_{it}\big) \; \geq 0 \,. \qquad (8)$$

We assume that $\frac{dQ}{dw} > 0$, and that $\frac{d^2Q}{dw^2} < 0$. Each additional unit of water applied has a positive impact on quantity produced, however, there are diminishing marginal returns for each unit of water applied. The marginal benefit of an additional unit of water, $P_t * \frac{dQ_{it}(w_{it}; z_{it}, s_{it}, r_{it}\Theta_{it})}{dw_{it}}$, is the resulting increase in quantity, multiplied by the price received for the crop. The marginal cost, $c_t * d_{it}$, is the energy price required to pump a unit of water, multiplied by the depth to groundwater, or the distance that the water must be pumped. The shadow price of a marginal increase in well capacity (λ) is the increase in future discounted profits that would result from the increase in well capacity. The shadow price of a marginal increase in depth to groundwater (η) is the decrease in future profits that the producer faces due to the increased depth to groundwater. As the dynamic producer makes decisions, they consider not only the marginal benefit and cost of pumping an additional unit of water in that time period, but they also consider the impact that an additional unit of water pumped in the current time period has on future profits. While the dynamic producer is considering the shadow price of increased well capacity and decreased depth to groundwater in future time periods, the magnitude of these shadow prices remains in question, and will have an impact on the amount of water that is extracted within the current time period.

We also assume that the cross derivative $\frac{d^2Q}{dw\,dz} > 0$. In words, increased well capacity is a compliment of production to water applied. As well capacity increases, producers are able to apply the water when it is most beneficial, and they are able to avoid irrigating during times when the marginal product of water applied is lower. Because of the complementary relationship between well capacity and water pumped, we hypothesize that well capacity increases the marginal product of water, and that increased well capacity will result in increased water pumped in a given year.

Given the increased cost that each additional unit of depth to groundwater imposes upon the producer, we anticipate that an increase in depth to groundwater will decrease the amount of water pumped. An increase in the depth to groundwater increases the marginal cost, without changing the marginal benefit, subsequently decreasing the optimal amount of water to be pumped. We hypothesize that an increase in the percentage of soil that is sandy will increase the water requirement for the crop, in turn impacting the production function. A shift in the production curve increases the marginal benefit of an additional unit of water, with $\frac{d^2Q}{dw\, ds} > 0$. Thus, we anticipate that as the percentage of soil that is sand increases, the amount of water that is pumped will also increase. We also assume that $\frac{d^2Q}{dw\ \ dr} < 0$. Precipitation and groundwater pumped are substitutes, as the crop receives an additional unit of precipitation, the need for groundwater decreases. Thus, we anticipate that additional precipitation will decrease the amount of groundwater pumped.

Myopic Decision Making Model

In a myopic decision making model, profits are being maximized in the current time period only, and the producer is no longer taking the state variables into account

$$\max_{w_{it}} \ \pi_{it} = P_t * Q_{it}(w_{it}; z_{it}, s_{it}, r_{it}, \Theta_{it}) - c_t * d_{it} * w_{it}. \qquad (9)$$

Decisions are made without regard for well capacity and depth to groundwater in future time periods. The myopic producer's first order condition can be expressed as:

$$\frac{d\pi}{dw} = P_t * \frac{dQ_{it}(w_{it}; z_{it}, s_{it}, r_{it}, \Theta_{it})}{dw_{it}} - c_t * d_{it} \ \leq 0 \qquad (10)$$

The myopic producer will pump groundwater until the marginal benefit of an additional unit of groundwater in the current time period, $P_t * \frac{dQ_{it}(w_{it}; z_{it}, s_{it}, r_{it}, \Theta_{it})}{dw_{it}}$, is equivalent to the marginal cost of pumping an additional unit of groundwater in the current time period, $c_t * d_{it}$. The benefit of increased well capacity in future time periods, alongside the costs of increased depth to groundwater in future time periods, are not factored into the pumping decision. We anticipate that this may lead to higher pumping in the current time period compared to the dynamic user, as the myopic user pumps additional water until the marginal benefit is equal to the lower marginal cost.

As previously mentioned, we hypothesize that owner operators are more likely to make decisions under the dynamic framework, as the state variables directly impact their future profits, and the value of their land. The difference in value between irrigated and dryland agriculture is substantial, and without adequate well capacity, or if the depth to groundwater becomes too large, profits to irrigated agriculture decrease, which in turn decreases the value of the owner's land. Tenants are not hypothesized to value the future farmland in the same way, which is why we have shown them to not consider the state variables, well capacity and depth to groundwater, in their production decisions.

It is possible, especially in areas with high well density, that an owner operator will conclude that their individual decision making will not be enough to influence future groundwater availability, and that they will therefore be more likely to embody the decision-making characteristics of a strategic decision maker. In this scenario, the strategically optimal amount of water to pump will potentially drift towards the myopic amount. As other groundwater users pump more water, the strategic groundwater extraction plan will converge upon the myopic pumping plan. However, if J=1 in the dynamic optimization equation above, then the strategic pumping strategy does not vary from the dynamically optimal pumping amount. As J increases, the strategically optimal amount begins to converge towards the myopic producer. The first order condition for the myopic user states that the operator will extract water until the marginal benefit is equal to the marginal cost. There is no reason the strategic user will not use more water than the myopic decision maker. A profit-maximizing individual's marginal cost of a unit of water will not exceed the marginal benefit. Thus, the amount of water the strategic user pumps is bound between the myopic amount, and the dynamically optimal amount.

The theoretical models also inform our hypothesis that owner operators will be more supportive of conservation, and more concerned about the long term availability of groundwater than tenant operators. As demonstrated in equations 8 and 9, well capacity and depth to groundwater are both a function of the amount of water that neighboring wells pump from the aquifer. Conservation policy would decrease the amount of water withdrawn from the aquifer by either implementing a limit on the amount of water that can be withdrawn, or increasing the marginal cost of pumping water. Given that $\frac{dQ}{dw} > 0$, this would decrease quantity in the current time period, in turn, decreasing profits in the current time period as well. The benefits of conservation would result in an increase in future well capacity and a decrease in depth to groundwater in the future. We assume $\frac{d\pi}{dz} > 0$, and that $\frac{d\pi}{dd} < 0$, so conservation has the potential to increase future profits. We hypothesize that tenants do not consider the shadow price of an increase in well capacity, or the shadow price of a decrease in depth to groundwater, so we anticipate that they will be more opposed to conservation implementation. Owner operators however, would see a decrease in current profits with an expected increase in future profits. While owner operator's support of future policy likely depends on the individual's discount rate, it is possible they would be more supportive of conservation than tenant operators, as they consider the benefits of increased well capacity and decreased depth to groundwater. Although owners would experience increased well capacity and decreased depth to groundwater compared to what they would experience without conservation policy, they will also face the cost of the conservation policy in the future. As we've discussed, conservation is costly, so it is possible the cost to owner operators in future time periods might dissuade owners from supporting any conservation policy, and they may be more opposed than tenant operators.

4. ECONOMETRIC APPLICATION

This section discusses our econometric models, as we analyze the impact that land tenure has on both behavior and on attitudes related to groundwater conservation. We estimate multiple versions of a log linear model with different sample sizes and additional explanatory variables to analyze the determinants of pumping. We then estimate the model again, incorporating spatial variables to further differentiate whether groundwater users are making decisions strategically. We then estimate a probit model with the varying levels of concern and support regarding conservation policies to understand the factors influencing conservation support. This section describes each of these models, the variables within the models, and the intuition behind the expected effect the explanatory variables are hypothesized to have on the independent variables.

Analysis of Groundwater Use

The amount of groundwater extracted is represented as a function of physical characteristics, which vary from well to well and are independent of the operator's control, and the tenure relationship the operator has with the well they are managing. Within this dataset, there are multiple wells operated by the same operator. In order to address this, we have assigned an operator ID to each individual who operates at least one well. We then cluster the standard errors based on this operator ID. This addresses correlation that is likely to occur between wells that are managed by the same operator, even if the wells do not share similar physical characteristics, the operator may use similar technology on the different wells they manage, or be generally prone to over or under apply water to the crops they are growing. Throughout the results section, the standard errors shown are the robust standard errors that have been clustered on operator ID. We first estimate the following econometric model, motivated by our theoretical analysis in the previous section, to analyze groundwater-pumping behavior

$$\begin{aligned} lnPump_{it} = \beta_0 &+ \beta_1 Owner\_User\_Diff_i + \beta_2 Tenant\_Operated_i \\ &+ \beta_3 lnWellCapacity_i + \beta_4 lnDepth2Water_i + \beta_5 PercentSand_i \\ &+ \beta_6 lnPrecip_{it} + \beta_7 2014 + \beta_8 2013 + \beta_9 2012 + \beta_{10} 2011 + e_i. \quad (11) \end{aligned}$$

The dependent variable is the natural log of water pumped at an individual well over the course of a growing season. $Owner\_User\_Diff_i$ indicates that someone other than the owner of the well is operating the well. We hypothesize that the coefficient on this variable will be positive, suggesting that certeris paribus, producers pump more from wells that they do not own. An individual who holds a property right to continue to use the well overtime may be more concerned about the long term stock of the resource, while the user without this property right may act without regard to the future value of the stock of the resource.

$Tenant\_Operated_i$ is a dummy variable that indicates an individual who does not own a well within the basin but is managing a well or wells. We hypothesize that this coefficient will be positive as well. Similar to the operator who is renting, the tenant not only has less economic interest in the long-term economic viability of the specific well that they are managing, but they may also have less interest in the long-term economic viability of the aquifer. Thus, they may be even more likely to make decisions myopically, without consideration of the future value of the resource.

The variable lnWellCapacity is the natural log of the well capacity for the individual well, which we expect to be positively correlated with the amount of water pumped. Higher well capacity increases the marginal product of water because more water can be pumped when the water is most needed. LnDepth2Water represents the natural log of depth to groundwater, which is expected to have an inverse relationship with the amount of water that is pumped, the larger the depth to groundwater, the more energy is required to withdraw water. Thus, the marginal cost of an additional unit of water increases alongside depth to groundwater. The percentage of soil that is categorized as sand is expected to be positively related to the log of water pumped as well, with sandy soil requiring additional water compared to clay soil in the region. We anticipate precipitation to be negatively related to water pumped, with an increase in precipitation decreasing the need for irrigation to meet the crop's water requirement. A dummy variable for each year, with the exception of 2015, is included to control for factors that are spatially uniform across the region, however may vary across time from year to year. For example, while the price of crops, and the price of inputs of production, energy prices, and temperature are mostly homogenous across space, especially given the region of this research, they may change from year to year.

Another variation of the model was estimated that restricted observations to wells for which we have survey data. The total number of observations used to estimate this model drops from 13,622 to 2,677. This iteration was estimated to ensure that the age and the family dummy variable were not just capturing a response bias with the second iteration of the model only including wells which had an associated returned survey. We expect the results to be consistent with the first iteration of the model, although the decrease in observations results in a decrease of statistical power.

The third iteration of the behavioral pumping model incorporates the operator's age, and whether the operator anticipates a family member will continue farming the land they are currently farming upon their retirement. We hypothesize age to be negatively correlated with water use. While a younger farmer may be maximizing profit over the next 30 years, an operator who is older may be nearing retirement and thus only maximizing their profits from the present through their retirement. Thus, the stock of the aquifer is less valuable to older producers who may not need it as an input for as long. It should be noted that some of this effect may be lost when considering how groundwater availability influences the price of the land. A decrease in groundwater availability would decrease the rent, or value of the land, which may impact operators uniformly despite differences in age. Another potential factor that could influence operators based on their age is that younger operators generally have a higher debt load compared to an older producer, which may decrease their ability to act dynamically. The dummy variable "famcont" indicates whether an individual expects their relatives to continue to farm after the operator retires. We expect this variable will also be negatively correlated with water use. We anticipate a higher concern for groundwater availability from these operators and thus, a corresponding increase in the application of conservation management principles. Thus, we expect farmers who have their children's future economic viability in mind may be more likely to make decisions dynamically. All independent variables from the first two iterations of the pumping model are included within this third iteration.

It is likely that the impact that each of the explanatory variables has on the amount of water pumped is dependent upon the hydrological constraints that a decision maker faces at their specific well. Wells were assigned to one of three bins, wells with a capacity of less than 500 gallons per minute, wells with a capacity between 500 and 800 gallons per minute, and wells with a capacity of more than 800 gallons per minute. While the expected sign on each of the explanatory variables are not anticipated to change across well capacity bins, we hypothesize the impact that each explanatory variable has will change dependent upon whether the well is in the low, medium, or high capacity bin. We hypothesize that well capacity will have a larger influence on water use for low capacity wells than it will have on either medium capacity wells or high capacity wells. As well capacity decreases, there is likely a point where the decision maker can no longer optimally manage their wells. So long as well capacity is above that threshold and the producer is capable of applying the necessary amount of water at specific time in order to optimally manage their pumping decisions, we expect to see a decreased importance of well capacity on decision making. We anticipate that well capacity is the dominant factor influencing pumping decisions for low capacity wells, however as this constraint is lifted we expect other variables, such as depth to groundwater, to become more influential. We also anticipate precipitation to decrease groundwater pumping more amongst high and medium capacity wells. These wells have the ability to apply enough water to meet the minimum crop requirement when water is most valuable to the crop. Increased well capacity allows farmers to turn off their wells during times of rain, when additional groundwater has a lower marginal value of production. They are able to do so with the knowledge that they will have the ability to meet the crop's water requirement throughout the season when additional water is more valuable.

As previously mentioned, the model is estimated again with spatial variables introduced to analyze groundwater pumping to see if groundwater users are acting strategically. The model was estimated with three additional variables, the number of wells that are within a one-mile radius of a given well, the number of wells the survey respondent indicated that they operated, and a variable that captured the interaction between these two terms. We propose that a positive relationship between water pumped and the number of wells within a one-mile radius, and a negative relationship between water pumped and the interaction term between the number of wells within a one-mile radius and the number of wells a respondent is operating, indicates that groundwater users are operating strategically. These variables indicate the degree of control that an individual can have on their future hydrologic circumstances. Fewer wells that are present within a hydrologically connected area, and more wells an individual is controlling within this hydrologically connected area, increase an individual's ability to manage the future groundwater stock.

Analysis of Groundwater Conservation Preferences

We also estimate the influence that each of the aforementioned independent variables had regarding conservation attitudes and policy support. We hypothesize that both concern about groundwater availability and support for specific policies are a function of tenure class, physical characteristics of the respondents' wells, and of personal factors that shape the way the respondent views conservation and the importance of a policy that would preserve and prolong the economic life and viability of the Ogallala aquifer.

The survey of Republican River Basin users and owners, described in more detail in the next section, solicited attitudes on groundwater concern, support for groundwater management districts involvement in conservation, and specific policy mechanisms. Probit models are estimated to investigate the relationship between the explanatory variables and the attitudes of the survey respondents. The first dependent variable was derived from a survey question that asked recipients how concerned they were about long term groundwater availability. The respondent had the option of answering very concerned, moderately concerned, slightly concerned, and not concerned. Using a probit model, we estimate the impact that demographics, tenure, and physical well characteristics have on the probability of being very concerned using the model

$$\Pr(VeryCon_i) = \beta_0 + \beta_1 Absentee\_Owner_i + \beta_2 Tenant\_Operator_i + \beta_3 lnWellCapacity_i + \beta_4 PercentSand_i + \beta_6 Age_i + \beta_7 famcont_i + \beta_8 Number\_Wells\_Permitted_i. \quad (12)$$

We classify the response as binary and we look at the likelihood that an individual is either very concerned about groundwater availability, or has a lower level of concern. We assign each survey recipient a tenure classification of absentee owner, owner operator, or tenant operator. $Absentee\_Owner_i$ is a dummy variable, and when positive indicates that the individual owns wells but does not operate any wells. $Tenant\_Operator_i$ is also a dummy variable, that indicates the respondent operates wells but does not own any wells within the Basin. We hypothesize that the owner operators will be the most concerned about groundwater availability. When contrasting owner operators to absentee owners, the owner operator is more likely to have an accurate understanding of the decreasing well capacities, and the threat that a lack of groundwater availability poses to the economic viability of agriculture in the region. The tenant operator may be more likely to make decisions myopically. As long as they have enough groundwater available in the current time period, they may be less likely to be worried about the future availability of groundwater. Thus, we expect that the dummy variables that indicate whether the respondent is either an absentee owner, or a tenant operator, to both be negative. We hypothesize that the coefficient on the log of well capacity will be negative, suggesting that the more water the respondent has available to them, the less worried they will be about groundwater availability. We anticipate that depth to groundwater will be positively related to concern about groundwater availability. The increased energy costs producers with a greater depth to groundwater are currently facing could generate a higher level of concern regarding groundwater availability. The percentage of soil that is classified as sandy soil is hypothesized to be positively related to concern as well. Sandier soil requires the application of more water, and producers who are required to use more water on their crops will be more negatively impacted by a decrease in groundwater availability, and subsequently more concerned about the availability of groundwater. As previously described, age decreases the future time periods over which an operator will expect to make production decisions, potentially devaluing the stock of the aquifer. Thus, we hypothesize age to have a negative impact on concern regarding groundwater availability. Concern is expected to be positively correlated with the dummy variable which indicates whether the family will continue to farm, as these respondents will likely have a higher concern because their relative's economic viability will be dependent upon the availability of groundwater in the future. The number of wells permitted is also anticipated to increase concern for the long-term availability of groundwater. Individuals who have more wells have more stock in the aquifer. Thus, they may be more concerned about the availability of groundwater in the future, as they would have more to lose from decreased groundwater availability.

The survey respondents were also asked whether they supported groundwater management districts working to develop strategies and practices that would seek to conserve groundwater. The respondents were given the opportunity to answer very supportive, somewhat supportive, somewhat opposed, or very opposed. Similar to the model that estimates concern, we model the dependent variable to either be very supportive, or not. We estimate using the same equation as the previous probit model, with a change in the dependent variable so that we are now estimating the probability a respondent is very supportive of their GWMD engaging in conservation policies. The hypothesized results do not vary from the previous model, we expect that the coefficients on Absentee_Owner, Tenant_Operator, lnWellCapacity, and Age to be negatively related to the probability that an individual is very supportive of groundwater management districts creating policy that supports conservation, and we expect depth to groundwater, percentage sand, the dummy variable indicating the family will continue to farm, and the number of wells permitted to be positively related to the probability a respondent supports GWMDs implementing conservation strategies.

Three additional models were estimated in order to evaluate the respondents' support for individual policies. Three policy mechanisms were explained within the survey, with each policy mechanism having the ability to be implemented at a level that would decrease groundwater pumping by 25 percent. The policy mechanisms were a quantity restriction, a fee on each acre foot pumped once the operator has exceeded a certain threshold, and a fee for each irrigated acre in production. Each estimation uses a probit model and the same independent variables as previously discussed for the concern and support estimation models. Our expectations for the direction of the coefficients also match the expectations provided for the prior models.

A final regression is estimated to analyze the impact land tenure, personal and family dynamics, and physical well characteristics have on supporting at least one of the aforementioned policies. The dependent variable is the probability that the respondent supports at least one of the management policies described above. The hypotheses on each coefficient do not change from the models that estimate support from the specific policies, however this model is run to determine if there is general policy support amongst owner operators as opposed to absentee owners and tenant operators that may have been lost in the noise of the individual policy regressions.

5. DATA

Our analysis utilizes data from a number of different sources. A survey was developed as a collaborative effort between the Water Preservation Partnership (WPP), the RRWCD, and a team of researchers at Colorado State University (CSU). The objective of the survey was to better inform the WPP, the RRWCD, and GWMDs on the practices and attitudes of groundwater users within their districts, and to aid in the development of future groundwater conservation strategies. Discussions between the

CSU researchers and members of the WPP produced a draft of the survey, which was "pre-tested" amongst members of each groundwater management district at the end of September 2016. Survey recipients first received an announcement about the survey in mid-October 2016. Then, in the first week of November 2016, the survey was mailed to 1,204 individuals who own or manage irrigated land within the Basin, using the list of addresses provided by the Colorado Groundwater Commission. A second survey was sent to individuals who had not responded by the first week of December. As of March 22nd, 2017, 275 partially or fully completed surveys have been received, resulting in a response rate of 22.8%. We also heard from 38 individuals who received the survey but indicated that they were not eligible to participate, as well as several individuals who did not complete the survey but indicated resistance to any groundwater management research proceeding within the Basin.

The Colorado Groundwater Commission provided well-level groundwater pumping records from 2011 to 2015 and also provided addresses for well owners and well operators within the Republican River Basin (Grimes 2016). From this dataset, we were able to determine the tenure classification of well owners and operators. An individual in this dataset could fall within multiple categories of ownership; there are individuals who own wells but are not the operator of any wells, there are owners who own wells and operate exclusively the wells they own, owners who own wells who operate some but not all of their wells, owners who operate their own wells in addition to some wells they do not own, and tenants who exclusively operate wells that they rent. We have classified each individual into one of three ownership groups. Absentee owners are classified as owners who do not operate any wells. While there may be owners who live within that Republican River Basin that fall within this category and thus do not fit the typical definition of an absentee owner, they are absent from the operational decision making processes regarding their wells. Owner operators are individuals who both own and operate wells. Some of the wells they own may be rented out to other operators, or they may renting some portion of the wells they are operating, however as long they both own and operate at least one well, they are categorized as owner operators. The third categorization are tenant operators, which are individuals who operate wells within the basin, however they do not own any wells themselves.

While survey recipients were separated into the aforementioned categories, the actual wells rather than individuals were categorized for the pumping models. First, a dummy variable was established indicating if the user of the well was different than the owner of the well. Then, wells that had a different owner and user were further differentiated, to indicate whether a well was operated by an owner operator who was not the owner of that specific well, or if the well was operated by a tenant operator who did not own any wells.

Our data set included other physical characteristics of the well including well capacity, depth to groundwater and soil characteristics that were used as independent variables to control for water use. Well capacity was provided by the Colorado Division of Water Resources (Kucera 2015) and depth to groundwater estimates were from the USGS (Flynn, 2009). The soil characteristics were gathered using the Soil Survey Geographic Database and were then transformed using Soil Data Viewer, an ArcGIS add-in (SSURGO). Our precipitation data was gathered from the Prism Climate Group (PRISM).

Table 1 displays the number of observations of groundwater wells that are operated by the owner, by an operator who is not the owner, and the number of wells that are operated by strictly tenant operators. Our dataset includes 2,765 unique wells that we were able to assign an operator ID. Of these wells 1,333 (48%) are operated by the owner of the well, 1,431 (52%) are operated by another operator, with 738 (27%) being operated by tenant operators. Observations extend across five years, which yields a total of 13,622 observations. Precipitation is represented in millimeters, and it is the precipitation that was received throughout the growing season. Well capacity, which is the amount of water that can be pumped per minute, varies substantially, ranging from 7.76 gallons per minute to 2,887 gallons per minute. While 7.76 gallons per minute is not enough to provide irrigation for a pivot by itself, there are times when multiple wells are used to irrigate the same field. Thus, it is possible that some wells do have extremely low capacities and are just used for supplemental irrigation. Depth to groundwater ranges from ten to 300 feet, with a mean of 156.1 feet. The percentage of the soil that is sand varies throughout the basin, from having zero percent of the soil be sand, to 98 percent of the soil being sand.

Regressions estimating the determinants of groundwater pumping that include the variables age and whether the family would continue to farm, and are thus restricted to wells that have had the owner or operator reply to our survey and provide an answer for the question regarding age and whether they anticipated their family to continue farming upon their retirement. The survey responses were linked to multiple observations, as respondents either owned or operated multiple wells, and there were multiple observations across time for each well. This decreased our observations to 2,677 wells over five years. As seen in Table 3, this slightly changes the proportions of our wells across different tenure classes, however the change is not substantial. There are 45% of the well observations in which the well is operated by the owner of the well, 55% of well observations in which the well is operated by an operator who is not the owner of the well, and 25% of observations in which the well is operated by a tenant operator. The summary statistics for the explanatory variables for both the second, third, and fourth iterations of the model estimating groundwater pumping can be found in Table 2.

The probit model estimates varying levels of groundwater concern and support for different groundwater conservation policies that would seek to conserve groundwater availability. While the independent variables do not change across these regressions, the dependent variables do change to capture the impact that tenure classification, select personal factors, and physical well characteristics have on concern and policy support. There are three different observation levels for these regressions, as the number of observations is a function of the number of people that answered each question, and there were a number of surveys that were returned partially complete. There are 628 observations where "Very Concerned" is the binary dependent variable, 617 observations where "Very Supportive" is the binary dependent variable, and 536 observations where support for specific policy mechanisms are the dependent variable. While the survey included a detailed explanation of the policy mechanisms, the decrease in observations is likely due to a number of respondents feeling they did not understand the policy mechanisms, or they did not want to provide comment on them. These regressions were then estimated again, assuming that individuals who answered the question regarding their level of concern, but did not answer the section on specific policies mechanisms, skipped this section because they were not in support of any of the policy mechanisms. It should also be noted that there was a small number of respondents who did not reply to the survey because they were strongly opposed to the possibly of any groundwater management policy. These individuals could not be included within the regression analysis, as they did not provide adequate information.

Table 3 displays the number of individuals surveyed in each tenure class, as well as a breakdown of the number of responses to each question by tenure class. Given the nature of how the specific policy questions were asked, the number of responses to each specific policy mechanism was consistent. Table 4 provides the summary statistics for the explanatory variables in the probit models. There is a decrease in observations for the probit models, as there are no longer observations across multiple years.

6. RESULTS

The following section provides the econometric results for the analysis that examines the determinants of groundwater use, as well as the determinants of policy support. The explanation of these results focuses on the variables of significance within our regressions, and provides some alternative hypotheses when variables had an effect that was counterintuitive to our expectations.

Analysis of Groundwater Use

The first column in Table 5 displays the results from the first iteration of the pumping model, where observations are not restricted to wells that have responded to the survey. For each coefficient in the model the standard errors are clustered on the operator ID. The tenant-operated dummy is not statistically different from zero and has a relatively high p value of 0.487. In addition, the coefficient is relatively small in economic terms, suggesting that a well pumped by a tenant operator would pump approximately two percent more than a well that was operated by an owner operator. The dummy variable that indicated that the operator of the well was not the owner of the well was also not significant and even smaller in magnitude. The coefficient on the natural log of precipitation was negative and significant as hypothesized, suggesting that a one percent increase in precipitation would lead to a 0.40 percent decrease in water pumped. Well capacity was positive and significant, indicating a one percent increase in well capacity results in a 0.68 percent increase in water pumped. The relationship between depth to groundwater was counter to what we had hypothesized, with a one percent increase in depth to groundwater resulting in a 0.17 percent increase in groundwater pumping. The percentage sand was positive and significant, suggesting soil that was one percent sandier, would result in an increase of pumping by 0.2 percent. Two of the year dummy variables were significant, suggesting that ceteris paribus, wells pumped 14.9 percent more in 2011, and 10.6 percent more in 2012 as opposed to the most recent year, 2015. It is possible that well capacity has decreased overtime, or that individuals have become more aware of decreasing aquifer levels due to the efforts of groups such as the Republican River Water Conservation District and the Water Preservation Partnership. It is also possible that these decreases are attributable to changes in prices of crops or of inputs necessary in the production of crops. Another explanation could be the timing of precipitation within these years. While cumulative precipitation across the growing season is controlled for, it is possible that the majority of the precipitation may have occurred too early or late in the years where groundwater pumping was highest.

Table 5 also contains the results of the same model, however observations are restricted to respondents who have answered both to the age and "will your family continue to farm" questions (although these variables are left out of the model that is in the second column of Table 5). Thus, our observations decrease from 13,652 to 2,677. Restricting the observations changes the sign on the coefficient on both the User_Owner_Diff variable and the Tenant_Operated variable, however they were both insignificant. The coefficient on the natural log of precipitation remained negative and significant, however the magnitude decreased indicating that a one percent increase in precipitation would lead to 0.25 percent decrease in pumping rather than a 0.39 percent decrease in pumping. The natural log of well capacity is very consistent with the first estimation, as the sign and significance do not vary, and the magnitude essentially does not vary, changing from 0.68 to 0.7 indicating that one percent increase in well capacity results in a 0.7 percent increase in groundwater pumping. The coefficient on depth to groundwater remains counterintuitive, with a one percent increase in depth to groundwater resulting in a 0.08 percent increase in groundwater pumping. The coefficient on PercentSand was unchanged by restricting the observations, continuing to have a significant and positive impact on groundwater pumping. The dummy variables for 2011 and 2012 remain significant, however the magnitude on both variables increased. The dummy variable for 2011 increased from 0.148 to 0.204, indicating that the wells within this subset pumped 20.3% more in 2011 than 2015. The dummy variable for 2012 indicated that wells within this subset of pumped 26.3 percent more than the same well in 2015. Within this model, the dummy variable for 2013 was significant as well, indicating that pumping was 17.2 percent higher than in 2015, ceteris paribus.

The results of the regression that includes both age and whether a farmer's family will continue to farm after they retire as independent variables are depicted as the third column within Table 5. While slight changes in magnitude of the remaining coefficients can be observed in Table 5, there were very small changes in the significance and interpretation on the control variables. The coefficients on both age and famcont were both insignificant. The coefficient on age indicates that a one-year increase in age decreases pumping by 0.003 percent. While we anticipated an increase in age resulting in an increase in pumping due to a decrease in the valuation of the stock of the aquifer over time, it is possible that younger operators facing higher debt loads are in need of higher and more consistent yields, and are thus observed to pump more. The dummy variable indicating that a family member was continuing farming upon the respondent's retirement was insignificant.

Table 6 displays the results of the binned regressions. Across the three regressions, the only tenure variable that was significant at even the ten percent level was the tenant operated variable in regression that used medium capacity wells. The coefficient indicated that tenant operators use 12 percent less water than owner operators who are operating wells that are not their own, however there is not a significant difference between tenant operators and owner operators who are operating their own wells. Well capacity did not have the anticipated impact across all three models. The coefficient on the natural log of well capacity for the regression using low capacity wells suggested that a one percent increase in well capacity lead to a 0.8 percent increase in groundwater pumped. The coefficient on medium capacity wells was smaller as anticipated, suggesting that a one percent increase in well capacity would lead to a 0.3 percent increase in groundwater pumping. The coefficient on well capacity for the regressions using high capacity observations diverged from expectations, with a one percent increase in well capacity lead to a 1.15 percent increase in water pumped. The coefficients on precipitation also met expectations within the low and medium capacity wells, however the results from the high capacity wells did not conform to our expectations. As we hypothesized, precipitation did not have a significant impact on pumping for low capacity wells. Amongst medium capacity wells, precipitation was significant, with a one percent increase in precipitation causing a 0.29 percent decrease in groundwater pumping. Amongst high capacity wells, precipitation was insignificant. We anticipated that medium and high capacity well operators would be more reactive to precipitation. While this appears to be the case with operators using medium capacity wells, it may not be the case for individuals operating high capacity wells. Depth to groundwater did have the anticipated impact across the three different models, as it was significant only amongst high capacity wells. We had hypothesized that as the well capacity constraint was decreased, the operators would be more attentive to other factors such as the marginal cost of pumping an additional unit of groundwater. The percentage of soil that is sand was positive and significant in each of the three models, however the impact of the variable was largest amongst low capacity wells and lowest amongst high capacity wells.

Table 7 contains the results from the model that incorporates spatial variables within the analysis. The results are very similar to the third iteration of the log linear pumping model, which included age and whether the family would continue farming after the operator retired. Well capacity, precipitation, percentage of soil that is sand, and the dummy variables for the year 2011, 2012, and 2013 were all significant and had very similar impacts in each iteration of the model. The three variables that were introduced to detect strategic decision-making were all insignificant. The number of wells within a mile radius, the number of wells a farmer was operating, and the interaction term between these two variables did not have a statistically significant impact on the amount of water that was pumped.

Analysis of Groundwater Conservation Preferences

The results of the first probit regression, which analyzed the probability an individual was very concerned about the long term availability of groundwater, along with the subsequent marginal effects can be found in Table 8. Contrary to our expectations, absentee owners were 16.4 percent more likely than owner operators to be very concerned about long-term groundwater availability. This is likely reflecting the concern an absentee owner has for the value of their assets overtime, as they realize that the value of their land is tied to groundwater availability. The marginal effects of being a tenant operator were consistent with what we had hypothesized, with tenant operators being 33.7 percent less likely than owner operators to be very concerned about long-term groundwater availability. Well capacity also had the hypothesized sign, with the coefficient indicating that a percent increase in well capacity, when all other independent variables are held constant at their respective means, results in a 12.7 percent decrease in the probability a respondent would be very concerned about groundwater availability. Consistent with our hypothesis, the marginal effects of age are negative as well, indicating that a one-year increase in the respondent's age results in a 1.10 percent decrease in the probability that the respondent is very concerned. The sign on the number of wells permitted was counter intuitive to our expectations, with a marginal effect of -0.016. This indicates that an additional well permitted decreases the probability of support for a policy by 1.61 percent. Depth to groundwater, the percentage of soil that was sandy, and the dummy variable that indicated the family was going to continue to farm, are insignificant.

The survey recipients were also asked about their support for groundwater management districts working to "develop and promote strategies and practices that seek to conserve groundwater in the Basin." Table 9 contains the results of the probit model, that analyze the impact of the aforementioned independent variables on whether or not the respondent was very supportive of groundwater management districts developing conservation strategies. Tenant operator was the only significant variable within this model. When holding all other variables constant at their respective means, tenant operators are 35.1 percent less likely than owner operators to be very supportive of their groundwater management district working to develop and promote conservation strategies compared to owner operators.

Table 10 condenses the results from each probit model that analyzed support for a specific policy mechanism at the 10 percent level, with the marginal effects from each individual model displayed alongside the probit results. Tenant operators are 10.1 percent less likely to support the irrigated acreage fee. While we had hypothesized that tenant operators would be less likely to support each of the policies, land tenure does not have a significant impact on support for the other two policy mechanisms that would be implemented at a level that would decrease pumping by 10 percent. The natural log of well capacity was significant for the quantity restriction at the 10 percent level with a marginal effect of -0.112. Thus, a one percent increase in well capacity decreases the probability of supporting the quantity restriction by 0.112 percent. Well capacity also had a significant influence on support for the volumetric fee, with a one percent increase in well capacity resulting in a 0.161 decrease in the probability an individual would support the volumetric fee. It is interesting that well capacity has a statistically significant influence on support for these two policies, but not the acreage fee. As we described when discussing our expectations, it is possible the quantity restriction and the fee that is assessed per acre-foot would not have an impact on individuals who use low capacity wells. For these wells to have an impact, water pumped has to exceed a threshold that many low capacity wells in the region do not exceed. Users of low capacity wells are more likely to have restricted acres and plant in rotation, which would further decrease water use, making it more unlikely for these policies to be binding. The acreage fee imposes a fee on each irrigated acre, regardless of the amount of water that is being used on that acre, while the quantity restriction and the volumetric fee more directly impact water use. Percentage sand is significant for only the quantity restriction. This is interesting, as it is likely individuals who have sandier soils that would be most adversely impacted by the quantity restriction, as they need more water than other soil types and the quantity restriction does not allow them any flexibility in order to meet these requirements.

The condensed probit results in Table 11 display support for each of the policy mechanism that could be implemented at a level that would decrease pumping by 25 percent. The results are very comparable to the models that measure policy support for individual policy mechanisms at the ten percent level. The tenure variables do not have a statistically significant impact on support for any of the policy mechanisms. The natural log of well capacity is negative and significant at the five percent level for both the quantity restriction and the acre-foot fee. The magnitude of the coefficients are -0.126 and -0.116 respectively, indicating a one percent increase in well capacity decreases the probability of a respondent supporting the quantity restriction by 0.126 percent and decreases the probability of supporting the acre-foot fee by 0.116 percent. This is consistent with the support for policy mechanisms being implemented at the 10 percent level. The natural log of depth to groundwater was significant and positive for the acre-foot fee at the 25 percent level, however it does not impact support for any other policy mechanism at either the 10 percent or 25 percent level in a way that is statistically significant. The number of wells permitted was negatively correlated with the probability a respondent would support the irrigated acreage fee. We had anticipated that the number of wells permitted would be positively correlated with policy support, as individuals with more wells would experience the benefits of conservation across each of the wells they owned. However, these individuals would also face the cost of conservation at each well, which may explain the decrease in policy support for the irrigated acreage fee. The remaining variables, which are percent sand, age, and whether the individual expects their family to continue farming, are not significant in influencing support for policies mechanisms being implemented at a level that would decrease pumping by 25 percent.

The final estimation combines the dependent variable from the previous models that estimate whether each individual policy mechanism would be supported, to analyze the impact that tenure, physical well characteristics, and select demographic characteristics would have on the probability a respondent would support at least one of the specific policy mechanisms. The results of the probit model can be found, with marginal effects, in Table 10. Absentee owners and tenant operators are not statistically different from owner operators in their support for at least one policy. The natural log of well capacity is significant at the five percent level, indicating that a one percent increase in well capacity would decrease the probability of supporting at least one policy by 13.4 percent. Age is statistically significant at the ten percent level, indicating that a one year increase in age results in a 0.7 percent change decrease in the probability a respondent would support at least one policy. The remaining variables, natural log of depth to groundwater, percent sand, and whether the family will continue upon the respondent's retirement, were insignificant.

7. CONCLUSION

Our research focuses on the impact that tenure has on groundwater use within the Republican River Basin, as well as the potential impact that it could have on policy implementation. Our hypothesis that operators would manage other people's property rights differently than their own, along with the hypothesis that owner operators are more likely to manage their wells dynamically is not supported by our results. Varying the sample size and introducing additional explanatory variables does not impact our findings, as we conclude tenure does not have a significant impact on groundwater use. Thus, we do not find support that owner operators are managing their own wells dynamically.

We then continued our analysis to determine if owner operators were acting strategically rather than myopically. The spatial variables that were introduced into the model were not statistically significant, which does not support strategic decision making. This view that groundwater users are making decisions myopically is consistent with the findings of Savage and Brozovíc (2011). Karp (1992) as well as Rubio and Casio (2002) had suggested that the difference between myopic and strategic pumping would be negligible. While this is likely true in areas with high well density, we find no evidence of divergence from myopic to strategic decision making in areas with less wells, or as an owner has more wells and thus the ability to have a larger influence on the aquifer. The physical constraints existing within the region are having a larger influence than other factors that would suggest strategic or dynamic decisions are being made. It also suggests that policies intended to sustain the economic life of the aquifer within the Republican River Basin in Colorado would have little or no benefit from accounting for tenure within their policy design.

While tenure does not appear to have a statistical influence on groundwater pumping within the Basin, there is heterogeneity amongst the tenure classes regarding concern over groundwater availability and support of groundwater management districts working to implement conservation policies and strategies. Tenant operators are

33.7 percent less likely to be very concerned about groundwater availability, as well as 35.1 percent less likely to be very supportive of groundwater management districts working on conservation policies. It is possible that statistical significance was lost in analyzing specific policies because individuals across all tenure classes were less likely to support these specific policies once they were shown the cost of a policy. As discussed in the results section, we had hypothesized that tenant operators would be less likely to be concerned, and less likely to support conservation policy. If tenant operators do not have a property right to use the aquifer overtime, it is not surprising that they are less likely to be concerned about the future availability of water, as they would have no right to use it. Instead, their short run financial considerations are driving their conservation preferences. It is also expected that tenant operators would be less likely to support a policy put forth by the groundwater management districts. Conservation is costly within this region. The tenant operators would be subject to a cost they are not currently facing, in order to prolong benefits they would be less likely to realize. Given the concern of absentee owners, and the lack of concern and support from tenant operators, it is likely that any effort from groundwater management districts to implement conservation policy will be met with additional resistance from tenant operators. While it is not clear the influence tenant operators will have on decision making regarding conservation policies, the degree of tenant approval required is likely to be important in determining whether or not these policies are approved. It was also interesting to note that absentee owners were actually more concerned about groundwater availability than owner operators, which we had not anticipated.

Our study is not without limitations. Our models that analyze the determinants of groundwater pumping do not currently account for the acreage that each well is irrigating. One farmer may be using two wells that are close to one another to irrigate two pivots, and apply 300 acre feet to each pivot. Another farmer could be using one well to irrigate two pivots and apply 200-acre feet to each pivot throughout the course of the season. Because each observation is made at the well level, it would appear that the farmer with two wells is using less water, while that farmer is actually withdrawing higher amounts of water from the aquifer. Currently, our models do not account or adjust for farmers who are using one well for multiple pivots. Our results may be biased if we are attributing myopic water pumping, which is a higher level of water pumped, to an individual who is actually using one well with dynamic pumping strategies to irrigate multiple pivots.

While our survey response rate of approximately 23 percent is fairly common for an agricultural producer survey, there is a decrease in the number of observations when we restrict the results to only individuals who answered enough of the survey questions to be included in our regression analysis. While we are assuming that a non-response to specific questions, particularly the policy support questions, do not indicate that the respondent is not supporting a policy but rather that they did not choose to fill that section out, there may be some individuals who skipped the section after reading through it and deciding they were strongly opposed to all potential policies. Thus, it is possible there are some non-responses, which would be better classified as a lack of support for any of the specific policies. Potentially more prevalent, is the issue of response bias within our survey. It is possible that our survey was more likely to garner replies from individuals who are either most concerned about groundwater availability, or most opposed to any policy that would disrupt their current operation. Thus, our results may be biased in two ways, either implying that individuals are more concerned about groundwater availability and more supportive than the population is, or that the sample is actually more opposed to governance because those who are most aggravated by the idea of groundwater strategies were more likely to reply.

There are several ways in which our survey analysis could be expanded upon. While our research analyzes the impact that tenancy has on groundwater use and attitudes related to groundwater governance within the Republican River Basin of Colorado, the Ogallala aquifer extends across eight different states. Given more time and resources, it would be interesting to obtain survey data from other states and analyze the groundwater use and attitudes across different regions.

While our research examines groundwater use and policy support across the entire Basin within Colorado, it is likely that any policies that are implemented would be incorporated at the groundwater management level, and that policies could vary between different groundwater management districts. There has not been econometric analysis which evaluates determinants of groundwater use or support within each specific groundwater management district.

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FIGURES AND TABLES

Figure 1. Region of Study

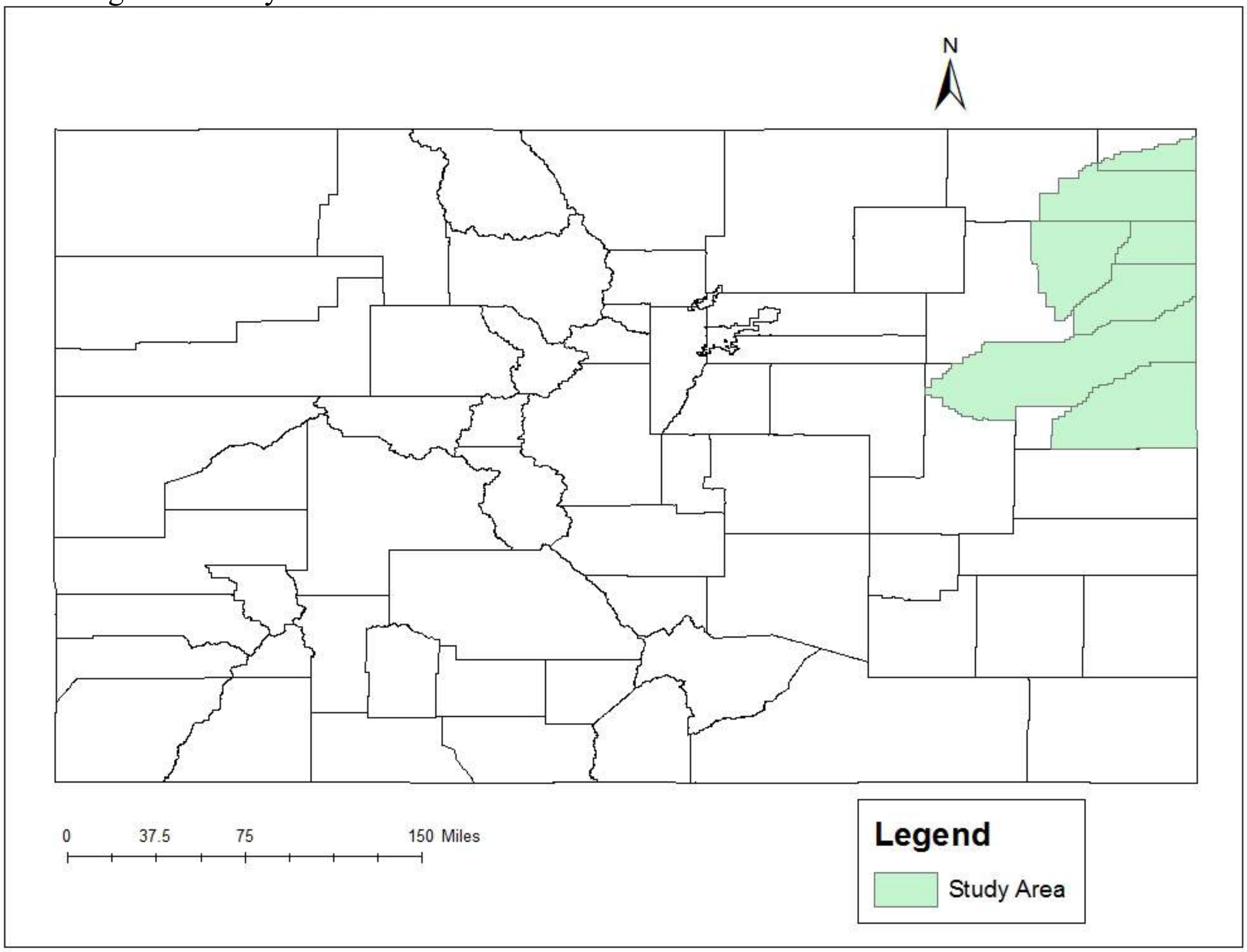

Figure 2. Wells By Tenure Classification

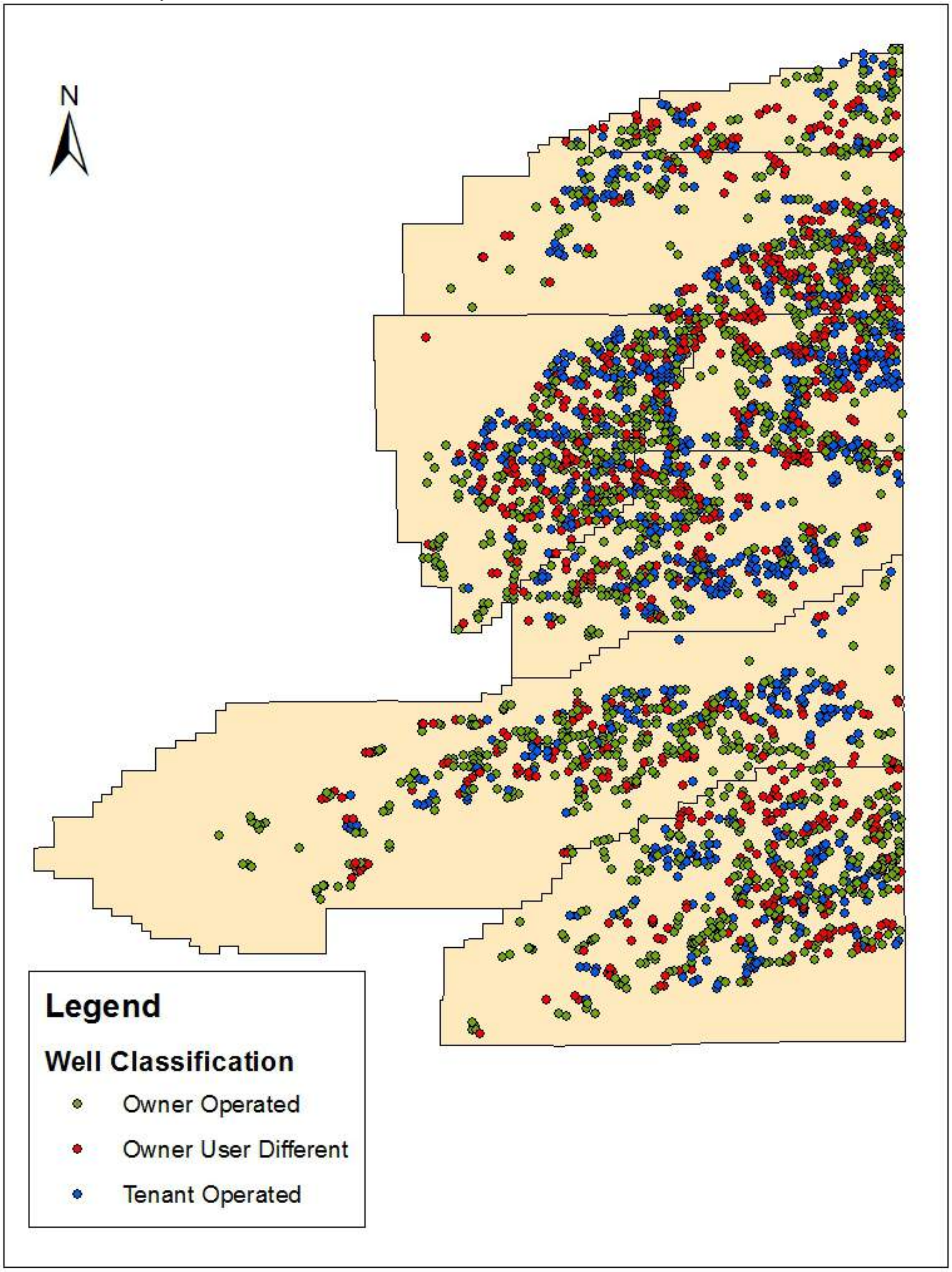

Figure 3. Surveyed Wells and Responses

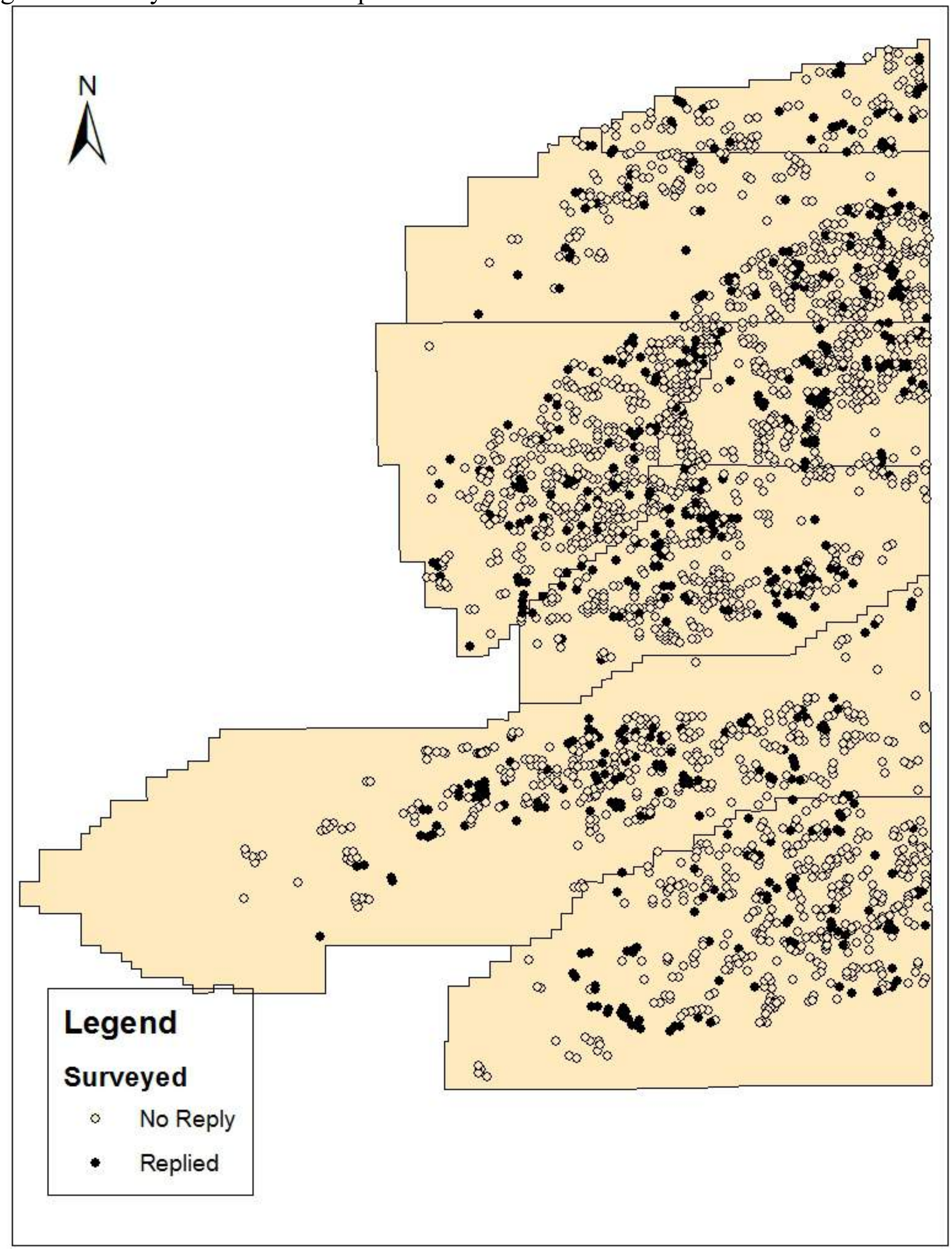

Table 1. Summary Statistics for Variables in the Full Pumping Analysis Regressions

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Precipitation (Millimeters)	13,622	295.2	108.9	96.34	551.9
Well Capacity (Gallons Per Minute)	13,622	739.5	349.4	7.760[1]	2,887
Depth to Groundwater (Feet)	13,622	156.1	52.55	10.00	300.0
Percent Sand	13,622	51.24	30.58	0	97.90
User Owner Different	13,622	0.522	0.500	0	1
Tenant Operated	13,622	0.269	0.443	0	1

Table 2. Summary Statistics for Variables in the Restricted Pumping Analysis Regressions

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Precipitation (Millimeters)	2,677	295.8	109.2	102.0	528.8
Well Capacity (Gallons Per Minute)	2,677	727.4	340.4	7.760	2,359
Depth to Groundwater (Feet)	2,677	154.7	49.50	10.00	300.0
Percent Sand	2,677	51.36	29.88	9.200	97.90
User Owner Different	2,677	0.554	0.497	0	1
Tenant Operated	2,677	0.246	0.431	0	1
Age (Years)	2,677	61.48	11.04	29	89
Family Continue	2,677	0.710	0.454	0	1
Mile Radius (Number of Wells)	2,677	4.173	1.995	1	12
Wells Used	2,677	8.697	8.488	0	36
Radius Used	2,677	38.99	50.74	0	420

[1] While this is too low of a well capacity to irrigate a field by itself, multiple wells can be used to irrigate the same field.

Table 3. Number of Individuals Surveyed by Land Tenure, and Response Rate

Number of People Surveyed: 1,203			
	Absentee Owner	Owner Operator	Tenant Operator
Number Surveyed	429	607	167
% of Total Surveyed	36%	50%	14%
Number of Responses to "Concern" Question	248		
	Absentee Owner	Owner Operator	Tenant Operator
Responses	79	140	29
% of Responses	32%	56%	12%
Response Rate	18%	23%	17%
Number of Responses to "Support" Question	240		
	Absentee Owner	Owner Operator	Tenant Operator
Responses	76	136	28
% of Responses	32%	57%	12%
Response Rate	18%	22%	17%
Number of Responses to Specific Policy Questions	190		
	Absentee Owner	Owner Operator	Tenant Operator
Responses	53	112	25
% of Responses	28%	59%	13%
Response Rate	12%	18%	15%

Table 4. Summary Statistics for the Probit Models

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Absentee Owner	628	0.197	0.398	0	1
Tenant Operator	628	0.126	0.332	0	1
Well Capacity (Gallons Per Minute)	628	718.8	345.1	7.76	2359
Depth to Groundwater (Feet)	628	154.4	50.59	10	300
Percent Sand	628	50.42	30.33	5.6	97.9
Age (Years)	628	62.82	11.96	29	97
Family Continue	628	0.710	0.454	0	1
Number of Wells Permitted	628	6.871	7.056	0	37

Table 5. Regression Results for Model Estimating Groundwater Pumping

VARIABLES	All Observations	Restricted Observations	Including Age and FamCont Variables
User_Owner_Diff	-0.00226	0.0747	0.0667
	(0.0278)	(0.0625)	(0.0672)
Tenant_Operated	0.0233	-0.0886	-0.0922
	(0.0335)	(0.0659)	(0.0672)
lnprecip	-0.398***	-0.251**	-0.259***
	(0.0518)	(0.104)	(0.0988)
lnWellCapacity	0.684***	0.706***	0.716***
	(0.0425)	(0.105)	(0.104)
lnDepth2Water	0.169***	0.0796	0.0871
	(0.0344)	(0.0843)	(0.0817)
PercentSand	0.00186***	0.00189**	0.00187**
	(0.000480)	(0.000799)	(0.000800)
d2014	0.00372	0.0213	0.0230
	(0.0204)	(0.0520)	(0.0515)
d2013	0.0259	0.172***	0.168***
	(0.0342)	(0.0607)	(0.0593)
d2012	0.104**	0.270***	0.263***
	(0.0474)	(0.0877)	(0.0870)
d2011	0.149***	0.203***	0.204***
	(0.0195)	(0.0495)	(0.0496)
Age			-0.00308
			(0.00233)
FamCont			0.0899
			(0.0580)
Constant	2.051***	1.439	1.515
	(0.430)	(1.078)	(1.025)
Observations	13,622	2,677	2,677
R-squared	0.352	0.387	0.391

Standard errors in parentheses, Standard errors clustered on Operator ID
*** p<0.01, ** p<0.05, * p<0.1

Table 6. Pumping Regressions by Well Capacity Classification

VARIABLES	Low Capacity Wells	Medium Capacity Wells	High Capacity Wells
User_Owner_Diff	0.283	0.0602	0.0256
	(0.171)	(0.0584)	(0.0650)
Tenant_Operated	-0.297	-0.122*	-0.0642
	(0.200)	(0.0704)	(0.0772)
lnprecip	0.0768	-0.287***	-0.210
	(0.290)	(0.0782)	(0.139)
lnWellCapacity	0.796***	0.297*	1.147***
	(0.244)	(0.173)	(0.0850)
lnDepth2Water	0.396	0.0378	-0.121*
	(0.247)	(0.0779)	(0.0689)
PercentSand	0.00437*	0.00202***	0.00116*
	(0.00237)	(0.000734)	(0.000680)
d2014	0.216**	-0.0120	-0.0778
	(0.0955)	(0.0581)	(0.0864)
d2013	0.532**	0.174***	0.0590
	(0.209)	(0.0600)	(0.0386)
d2012	0.601*	0.292***	0.224***
	(0.315)	(0.0785)	(0.0763)
d2011	0.421***	0.207***	0.0583
	(0.112)	(0.0503)	(0.0826)
Age	-0.00677	-0.000152	0.00101
	(0.00494)	(0.00253)	(0.00246)
famcont	0.101	0.0716	0.0114
	(0.157)	(0.0641)	(0.0633)
Constant	-2.477	4.451***	-0.808
	(2.421)	(1.116)	(1.257)
Observations	629	1,090	958
R-squared	0.272	0.229	0.445

Standard errors in parentheses, Standard Errors Clustered on Operator ID
*** p<0.01, ** p<0.05, * p<0.1

Table 7. Pumping Regression, Spatial Variables included

VARIABLES	
User_Owner_Diff	0.0389
	(0.0571)
Tenant_Operated	-0.0609
	(0.0684)
lnprecip	-0.252**
	(0.104)
lnWellCapacity	0.705***
	(0.107)
lnDepth2Water	0.0994
	(0.0829)
PercentSand	0.00179**
	(0.000808)
d2014	0.0218
	(0.0515)
d2013	0.172***
	(0.0622)
d2012	0.269***
	(0.0929)
d2011	0.203***
	(0.0493)
Age	-0.00261
	(0.00252)
famcont	0.0815
	(0.0595)
MileRadius	0.0158
	(0.0189)
Wells_Used	0.00739
	(0.0103)
Radius_Used	-0.000801
	(0.00144)
Constant	1.367
	(1.017)
Observations	2,677
R-squared	0.393

Standard errors in parentheses, Standard Errors Clustered on Operator ID
*** p<0.01, ** p<0.05, * p<0.1

Table 8. Probit Results, Dependent Variable: Concern about Long-term Availability of Groundwater

VARIABLES	(1) Probit Very Concerned	(2) Marginal Effects
AbsenteeOwner	0.543*	0.164*
	(0.316)	(0.0944)
TenantOperator	-1.114***	-0.337***
	(0.348)	(0.0928)
lnWellCapacity	-0.422***	-0.127***
	(0.156)	(0.0471)
lnDepth2Water	-0.294	-0.0889
	(0.267)	(0.0807)
PercentSand	0.00439	0.00133
	(0.00327)	(0.000989)
Age	-0.0363***	-0.0110***
	(0.0118)	(0.00318)
famcont	-0.00617	-0.00186
	(0.282)	(0.0852)
numwells_perm	-0.0534***	-0.0161***
	(0.0197)	(0.00558)
Constant	7.080***	
	(1.786)	
Observations	628	628

Standard errors in parentheses, Standard Errors Clustered on Respondent ID
*** p<0.01, ** p<0.05, * p<0.1

Table 9. Probit Results, Dependent Variable: Support for Groundwater Management Districts Working to Develop Groundwater Conservation Strategies

VARIABLES	(1) Probit Very Supportive	(2) Marginal Effects
AbsenteeOwner	-0.315	-0.115
	(0.277)	(0.101)
TenantOperator	-0.959***	-0.351***
	(0.358)	(0.125)
lnWellCapacity	0.0883	0.0324
	(0.135)	(0.0493)
lnDepth2Water	0.114	0.0416
	(0.216)	(0.0788)
PercentSand	-0.000845	-0.000310
	(0.00336)	(0.00123)
Age	0.00135	0.000495
	(0.0106)	(0.00390)
famcont	-0.124	-0.0452
	(0.308)	(0.113)
numwells_perm	0.0140	0.00513
	(0.0239)	(0.00869)
Constant	-1.268	
	(1.576)	
Observations	617	617

Standard errors in parentheses, Standard Errors Clustered on Respondent ID
*** p<0.01, ** p<0.05, * p<0.1

Table 10. Probit Results, Dependent Variables: Support for Specific Policy Mechanisms that Seek a 25 Percent Reduction in Groundwater Use

VARIABLES	Quantity Restriction Probit	Quantity Restriction Marginal effects	Volume Fee Probit	Volume Fee Marginal effects	Irrigated Acreage Fee Probit	Irrigated Acreage Fee Marginal Effects
AbsenteeOwner	0.250	0.0764	-0.230	-0.0661	-0.706*	-0.0753
	(0.312)	(0.0929)	(0.380)	(0.110)	(0.409)	(0.0516)
TenantOperator	-0.000611	-0.000187	0.0573	0.0165	-0.353	-0.0377
	(0.377)	(0.115)	(0.388)	(0.111)	(0.504)	(0.0541)
lnWellCapacity	-0.412**	-0.126**	-0.403**	-0.116**	-0.118	-0.0126
	(0.168)	(0.0495)	(0.176)	(0.0487)	(0.157)	(0.0169)
lnDepth2Water	0.221	0.0674	0.602**	0.173**	0.501	0.0534
	(0.240)	(0.0735)	(0.278)	(0.0796)	(0.461)	(0.0533)
PercentSand	-0.00458	-0.00140	-0.000342	-9.83e-05	0.0100*	0.00107*
	(0.00413)	(0.00124)	(0.00410)	(0.00118)	(0.00520)	(0.000620)
Age	-0.00621	-0.00190	-0.00264	-0.000761	0.0110	0.00118
	(0.0116)	(0.00358)	(0.0130)	(0.00376)	(0.0119)	(0.00132)
famcont	0.365	0.112	0.288	0.0830	-0.608	-0.0649
	(0.291)	(0.0908)	(0.311)	(0.0910)	(0.375)	(0.0422)
numwells_perm	-0.0239	-0.00729	-0.0167	-0.00482	-0.142***	-0.0151***
	(0.0221)	(0.00669)	(0.0232)	(0.00662)	(0.0376)	(0.00529)
Constant	1.376		-1.059		-3.299	
	(1.755)		(1.948)		(3.110)	
Observations	536	536	536	536	536	536

Standard errors in parentheses, Standard Errors Clustered on Respondent ID
*** p<0.01, ** p<0.05, * p<0.1

Table 11. Probit Results, Dependent Variable: Support for at Least One Policy Mechanism

VARIABLES	Probit	Marginal Effects
AbsenteeOwner	0.136	0.0477
	(0.336)	(0.118)
TenantOperator	-0.342	-0.120
	(0.354)	(0.122)
lnWellCapacity	-0.411***	-0.144***
	(0.145)	(0.0491)
lnDepth2Water	0.211	0.0741
	(0.223)	(0.0777)
PercentSand	0.000694	0.000243
	(0.00357)	(0.00125)
Age	-0.0200*	-0.00701*
	(0.0110)	(0.00364)
famcont	-0.370	-0.130
	(0.341)	(0.117)
numwells_perm	-0.0257	-0.00902
	(0.0249)	(0.00852)
Constant	3.551**	
	(1.603)	
Observations	536	536

Standard errors in parentheses, Standard Errors Clustered on Respondent ID
*** p<0.01, ** p<0.05, * p<0.1