6

STRATEGIC BEHAVIOR AND REGULATION OVER TIME AND SPACE

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Introduction

The management of groundwater resources for use in agriculture is an issue that reaches far and wide; many of the world's most productive agricultural basins depend on groundwater and have experienced declines in water table levels. Increasing competition for water from cities and environmental needs, as well as concerns about future climate variability and more frequent droughts, have caused policymakers to look for ways to decrease the consumptive use of water.

There is a socially optimal rate of extraction that can be modeled, measured, and achieved through policy and a complete definition of the property rights that govern groundwater. Social optimality can incorporate environmental amenities that provide value to people, ecosystems, or environments. Complete, measured, enforceable, and enforced property rights that consider the physical properties of the resource will induce the socially optimal rate of extraction in many cases. Where externalities occur, whether they are caused by the physical movement of water, by environmental damages or benefits, or by other causes, well thought-out policy can provide the incentives to move an individual's extraction path back to the socially optimal one.

There are two main reasons why the farmers may be over-pumping relative to what would be the socially optimal water pumping. First, owing to institutional reasons farmers may not be optimizing dynamically: they might not be considering the effects of current pumping on the amount of water that would be available to pump in the future. For example, as we explain below, the prior appropriation doctrine is an institution that distorts the incentive to optimize dynamically over the life of the resource, because farmers are unable to bank any unused portions of the water allocation in a particular year for use in future years. The second reason farmers may be over-extracting the resource is owing to a common pool resource problem: because farmers are sharing the aquifer with other farmers, other farmers' pumping affects the amount of water they have available to pump.

In this chapter we discuss our research on several aspects of strategic behavior and regulation over time and space. The first aspect we discuss is the behavioral response to voluntary, incentive-based water conservation programs for irrigated agriculture. These programs are often considered win–win policies; their objective is to reduce the consumptive use of water for agriculture, and they also often contribute to an increase in the earning potential of farms through the yield-increasing effect of efficient irrigation technology (Cox, 2013). For this reason, these programs are extremely popular and politically feasible, especially where the resource is considered scarce. However, when behavioral responses of the irrigator are ignored, such policies can have unintended or even perverse consequences. In Pfeiffer and Lin (2014), we examine the effect of programs that subsidize efficient irrigation technology on water extraction. Our results show that programs that subsidize efficient irrigation technology cause farmers to respond by switching to more water intensive crops, thereby increasing, not decreasing, water extraction.

The second aspect of strategic behavior and regulation over time and space we discuss is how the prior appropriation doctrine affects dynamic optimality. Groundwater users extract water under an institutional setting that governs their property rights to the groundwater and affects constraints they face and the choices they make. A variety of property rights doctrines and institutions governing groundwater have evolved in the western United States. Many more institutions, both formal and informal, are in place in other locations around the world. Our focus is on Kansas, a state that overlies a portion of the High Plains Aquifer. Current water rights in Kansas follow the prior appropriation doctrine. The prior appropriation doctrine allots water rights based on historical use, with priority going to those who claimed their right first. Appropriation contracts are stated in terms of a maximum acre-feet of extraction per year with a "use it or lose it" clause. Farmers must use their allocation each year and are unable to bank any unused portions of the water allocation in a particular year for use in future years. However, since the groundwater is in part a nonrenewable resource, since the availability of water is stochastic, since demand for water is greater when it is less available, farmers could operate in a more dynamically efficient manner if the appropriator could use less water in some years and more in others. In Pfeiffer and Lin (2013), we develop an empirical model to test whether groundwater users faced with the prior appropriation doctrine are behaving in a manner consistent with the Hotelling model for dynamically optimal nonrenewable resource extraction.

The third aspect of behavior and regulation over time and space we discuss is strategic behavior in the face of spatial externalities. One reason farmers over-extract water is due to a common pool resource problem: they share the aquifer with other farmers, and thus other farmers' pumping affects water availability. This property gives rise to a spatial externality whereby pumping by one user affects the extraction cost and total amount that is available to other nearby users. In Pfeiffer and Lin (2012), we empirically examine whether the amount of water one farmer extracts depends on how much water his neighbor extracts. Our results provide evidence of a spatial externality that causes farmers to over-extract water.

Our research focuses exclusively on the groundwater used for agriculture in the High Plains (Ogallala) Aquifer system of the Midwestern United States. There, 99 percent of the water extracted is used for crop production; the remaining 1 percent is used for livestock, domestic, and industrial purposes. The economy of the region is based entirely on irrigated agriculture. The corn, soybeans, alfalfa, wheat, and sorghum grown there are used for local livestock production or exported from the region. The small local communities support the agricultural industry with farm implement dealers, schools, restaurants, and other services. The state governments are also greatly concerned with supporting their agricultural industry.

We first describe the High Plains Aquifer in Kansas and the data we use for our research, and then proceed to discuss the three aspects of strategic behavior and regulation over time and space in turn.

The High Plains Aquifer in Kansas

Use of the High Plains Aquifer system, located in the Midwestern plains of the United States, began in the late 1800s but greatly intensified after the "Dust Bowl" decade of the 1930s (Miller and Appel, 1997). Aided by the development of high capacity pumps and center pivot systems, irrigated acreage went from 1 million acres in 1960 to 3.1 million acres in 2005, and accounts for 99 percent of all groundwater withdrawals (Kenny and Hansen, 2004). Irrigation converted the region from the "Great American Desert" into the "Breadbasket of the World."[1]

The High Plains Aquifer underlies approximately 174,000 square miles, and eight states overlie its boundary. It is the principle source of water in the Great Plains region of the United States. Also known as the Ogallala Aquifer, the High Plains Aquifer system is now known to include several other aquifer formations. The portion of the aquifer that underlies western Kansas, however, pertains mainly to the Ogallala, and this is why the name persists.

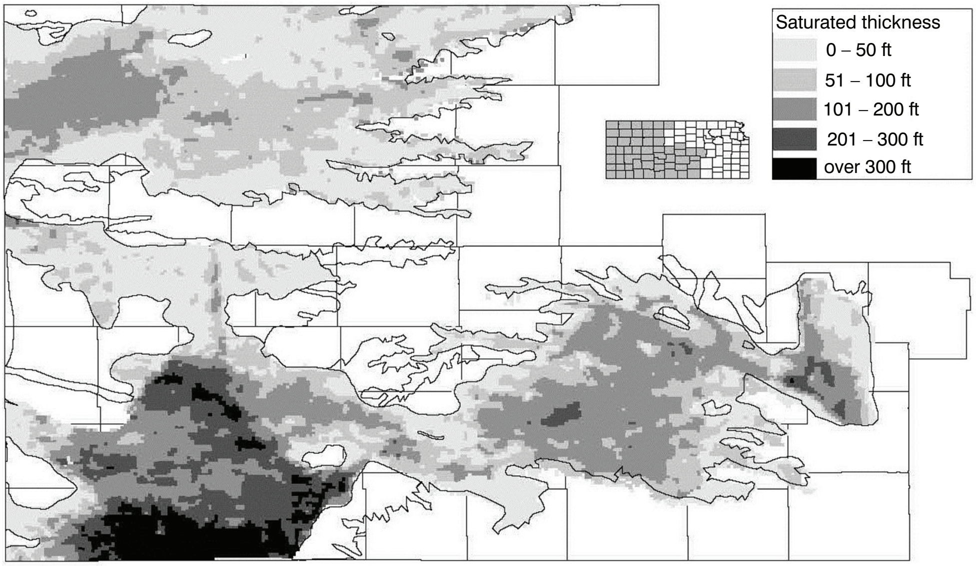

Figure 6.1 Predevelopment saturated thickness of the Kansas portion of the High Plains Aquifer (source: Kansas Geological Survey*)*

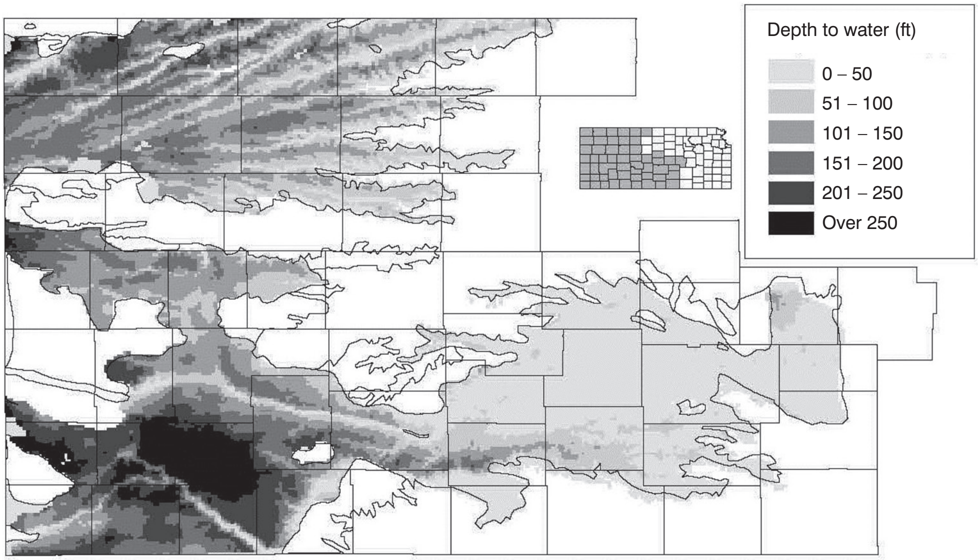

Figure 6.2 Average 2004–2006 depth to groundwater in the Kansas portion of the High Plains Aquifer (source: Kansas Geological Survey.)

The High Plains aquifer is underlain by rock of very low permeability that creates the base of the aquifer. The distance from this bedrock to the water table is a measure of the total water available and is known as the saturated thickness. The saturated thickness of the High Plains aquifer in Kansas ranges from nearly zero to over 300 feet (Buddemeier, 2000). Figure 6.1 shows the predevelopment saturated thickness of the Kansas portion of the High Plains Aquifer.

The depth to water is the difference between the altitude of the land surface and the altitude of the water table. In areas where surface and groundwater are hydrologically connected, the water table can be very near to the surface. In other areas, the water table is much deeper; the depth to water is over 400 feet below the surface in a portion of southwestern Kansas (Miller and Appel, 1997). Figure 6.2 shows the average 2004–2006 depth to groundwater in the Kansas portion of the High Plains Aquifer.

Recharge to the Kansas portion of the High Plains aquifer is primarily by percolation of precipitation and return flow from water applied as irrigation. The rates of recharge vary between 0.05 and 6 inches per year, with the greatest rates of recharge occurring where the land surface is covered by sand or other permeable material (Buddemeier, 2000).

Irrigation accounts for 99 percent of all groundwater withdrawals. The main crops grown in western Kansas, in order of decreasing water intensiveness, are alfalfa, corn, soybean, grain sorghum, and wheat. Corn production accounts for more than 50 percent of all irrigated land (Buddemeier, 2000); in 2005, the last year of our data set, corn production accounted for 40.0 percent of the irrigated land. Soil types and access to high volumes of irrigation water determine the suitability of a particular piece of land to various crops.

Data

We use a rich data set for our empirical analyses of strategic behavior and regulation over time and space. Kansas has required the reporting of groundwater pumping by water rights holders since the 1940s, although only data from 1996 to the present are considered to be complete and reliable. The data are available from the Water Information Management and Analysis System (WIMAS). Included are spatially referenced pumping data at the source (well or pump) level, and each data point has the farmer, field, irrigation technology, amount pumped, and crops grown identified. A sample of about 9,000 points of diversion for each of the 10 years from 1996 to 2005 is used for the analysis. We combine this data with spatial data sets of recharge, water bodies, and other geographic information.

The United States Geological Survey's (USGS's) High Plains Water-Level Monitoring Study maintains a network of nearly 10,000 monitoring wells. Data from these wells will be used to estimate yearly water levels. The USGS also has information on hydroconductivity, and precipitation data come from the PRISM Climate Group (2014). Relevant information from the geographic files will be captured at the points of diversion (well) level using ArcGIS. There are about 8,000 sampled points of diversion for each of the 10 years from 1996 to 2005.

The crop price data we use are a combination of spring futures contracts for September delivery for commodities with futures contracts and average price received for crops without futures contracts. Futures prices are from the Commodity Research Board (CRB), and price received is from the U.S. Department of Agriculture (USDA) Economic Research Service. Crop price ratios are constructed for the estimation and consist of the crop price divided by a weighted sum of the prices of all crops. The weights used are the average proportions of irrigated acres planted to each crop over the 1996 to 2005 time period in the counties included in the estimation.

Natural gas prices come from the U.S. Energy Information Administration, and are used for irrigators in counties with natural gas production. In other areas, the price of electricity is used as the price of energy. Over 50 percent of the acres irrigated from groundwater wells in Kansas are powered by natural gas (FRIS, 2004).

Soil characteristics come from the Web Soil Survey of the USDA Natural Resources Conservation Service.

We use this data to empirically analyze whether programs that subsidize efficient irrigation technology decrease water extraction, whether groundwater users faced with the prior appropriation doctrine are behaving in a manner consistent with the Hotelling model for dynamically optimal nonrenewable resource extraction, and whether the amount of water one farmer extracts depends on how much water his neighbor extracts. We now describe each of these empirical analyses in turn.

Behavioral response to incentive-based water conservation programs

In many places, policymakers have attempted to decrease rates of extraction through incentive-based water conservation programs. Between 1998 and 2005, the state of Kansas spent nearly US$6 million on incentive programs, such as the Irrigation Water Conservation Fund and the Environmental Quality Incentives Program, to fund the adoption of more efficient irrigation systems. Such programs paid up to 75 percent of the cost of purchasing and installing new or upgraded irrigation technology, and much of the money was used for conversions to dropped nozzle systems (NRCS, 2004). These policies were implemented under the auspices of groundwater conservation, in response to declining aquifer levels occurring in some portions of the state due to extensive groundwater pumping for irrigation (O.A.M.A. Committee, 2001).

Voluntary, incentive-based water conservation programs for irrigated agriculture are often billed as policies where everyone gains. These programs are politically feasible, farmers are able to install or upgrade their irrigation systems at a reduced cost, resulting in substantial increases in profits, less groundwater is "wasted" through runoff, evaporation, or drift, marginal lands can be profitably retired, and farmers can choose whether to participate. However, such policies can have unintended, even perverse, consequences.

In recent work (Pfeiffer and Lin, 2014), we find that policies that encourage the adoption of more efficient irrigation technology may not have the intended effect. Irrigation is said to be "productivity enhancing"; it allows the production of higher value crops on previously marginal land. Thus, a policy of subsidizing more efficient irrigation technology can induce a shift away from dry-land crops to irrigated crops. They may also induce the planting of more water-intensive crops on already irrigated land, as by definition, more efficient irrigation increases the amount of water the crop receives per unit extracted.

Similarly, land and water conservation and retirement programs may not necessarily reduce groundwater extraction, although they are billed as such. An example of a land retirement program is the Conservation Reserve Program (CRP) created by the federal government in 1985 to provide technical and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner (USDA 2014). These programs include payments to landowners to retire, leave fallow, or plant non-irrigated crops on their land. Such programs operate on an offer-based contract between the landowner and the coordinating government agency. The contractual relationship is subject to asymmetric information, and adverse selection may arise because the landowner has better information about the opportunity cost of supplying the environmental amenity than does the conservation agent. There is substantial evidence that farmers enroll their least productive, least intensively farmed lands in the programs while receiving payments higher than their opportunity costs, thus accruing rents. It is quite unlikely that an irrigated parcel, which requires considerable investment in a system of irrigation (which, in turn, enhances the productivity of the parcel), will be among a farmer's plots with the lowest opportunity cost and thus enrolled in the program. Instead, farmers may opt to enroll non-irrigated plots in the CRP, which does not have any effect on the amount of irrigation water extracted.

In our study, which has recently been cited in the *New York Times* (Wines, 2013), we focus on incentive-based groundwater conservation policies in Kansas and find that measures taken by the state of Kansas to subsidize a shift toward more efficient irrigation systems have not been effective in reducing groundwater extraction. The subsidized shift toward more efficient irrigation systems has in fact increased extraction through a shift in cropping patterns. Better irrigation systems allow more water-intensive crops to be produced at a higher marginal profit. The farmer has an incentive to both increase irrigated acreage and produce more water-intensive crops.

We find similar results in our analysis of the effects of land and water conservation and retirement programs on groundwater extraction. Theoretically, we know that because the programs are offer-based, farmers will enroll their least productive land. Our empirical results support this conclusion; we find essentially no effect of land conservation programs on groundwater pumping, which occurs, by definition, on irrigated, and thus, very productive land.

How the prior appropriation doctrine affects dynamic optimality

Groundwater users extract water under an institutional setting that governs their property rights to the groundwater and affects the constraints they face and the choices they make. The hydrological characteristics of an aquifer affect the way that property rights over its water should be defined. For example, if water flows easily in an aquifer, the inefficiencies associated with the exploitation of common property resources are more likely (Dasgupta and Heal, 1979; Eswaran and Lewis, 1984). Additionally, the amount of recharge that an aquifer receives helps determine the economically efficient extraction path. Because the portion of the High Plains aquifer that lies south of Nebraska receives very little recharge, it is least partially a nonrenewable resource and its social welfare maximizing extraction path can be described by a Hotelling-like model (Hotelling, 1931).

Our focus is on Kansas, a state that overlies a portion of the High Plains Aquifer. Kansas is the only state where a rich set of data on the recent history of groundwater extraction is available. Current water rights in Kansas follow the prior appropriation doctrine. Before 1945, Kansas applied the common law of absolute ownership doctrine to groundwater. Water rights were not quantified in any way (Peck, 2007). In 1945, following multiple conflicts between water users and several major water cases that reached the Kansas Supreme Court, the "Arid Region Doctrine of Appropriation" was adopted, which permitted water extraction based on the principle of "first in time, first in right" (Peck, 1995).

The earliest appropriators of water maintain the first rights to continue to use water in times of shortage or conflict. The water right comes with an abandonment clause; if the water is not used for beneficial purposes for longer than the prescribed time period, then it is subject to revocation (Peck, 2003). To obtain a new water right, an application stating the location of the proposed point of diversion, the maximum flow rate, the quantity desired, the intended use, and the intended place of use must be submitted to and approved by the Department of Water Resources (Kansas Handbook of Water Rights, n.d.). Since 1945, Kansas has issued more than 40,000 groundwater appropriation permits (Peck, 1995).[2] The permits specify an amount of water that can be extracted each year and are constant over time.

Through the 1970s, the period of intensive agricultural development in Kansas, groundwater pumping permits were granted to nearly anyone who requested them. Some permits are as old as 1945, but the majority (about 75 percent) were allocated between 1963 and 1981.

In the early 1970s, it was recognized that Kansas's groundwater resources were being depleted at a rapid rate in some locations. By 2008, in parts of southwestern Kansas, the water table had declined by over 150 feet since predevelopment.[3] This area was the first to be intensively developed, and continues to have the highest average extraction per square mile (Wilson et al., 2002).

In 1972, owing to concerns that the aquifer was over-appropriated, Kansas created five groundwater management districts (GMDs). The GMDs regulate well spacing and prohibit new water extraction within a designated radius of existing wells, which varies by GMD. The adoption of the prior appropriation doctrine, together with the development of GMDs to regulate new appropriations of water rights, arguably eliminated uncontrolled entry and the resulting over-exploitation commonly associated with common property resources. However, appropriation contracts distort the incentive to optimize dynamically over the life of the resource, because the farmer is essentially guaranteed his appropriated amount of water until the resource becomes so scarce that it is no longer economical to pump.

In ongoing work (Pfeiffer and Lin, 2013), we investigate how farmers manage groundwater over time and under an existing property rights regime. Specifically, our empirical analysis focuses on the portion of western Kansas that overlies the High Plains (Ogallala) Aquifer. An area with a relatively well-defined rights system, Kansas has used the doctrine of prior appropriation to govern the management of groundwater since 1945. Hotelling (1931) argues that the socially optimal rate of extraction of a nonrenewable resource over time is achieved in a competitive market equilibrium, provided that the social discount rate equals the market interest rate and that there are no market failures, such as externalities or incomplete property rights. The prior appropriation doctrine is an example of an incomplete property rights system, and thus may distort the incentive of a groundwater user to manage a resource dynamically, causing extraction to occur at a rate faster than is socially optimal.

We develop an empirical model to test whether groundwater users faced with the prior appropriation doctrine are behaving in a manner consistent with the Hotelling model for dynamically optimal nonrenewable resource extraction. In particular, do groundwater managers (individual farmers, in this case) consider the scarcity rent or shadow value of their resource when making extraction decisions? Or, do other behavioral assumptions, such as myopic optimization, provide a better basis for explaining their behavior? This is one of the first studies to empirically test the hypotheses of the theoretical groundwater management literature.

We find that despite the incentives given to groundwater users to pump their maximum allowable amount in each year by the prior appropriation doctrine, farmers extract water consistent with a dynamic model of resource extraction. While producers are allotted a time-invariant maximum amount that they can extract each year, they still consider the effects of recharge, their remaining stock, pumping by nearby neighbors that may affect their stock in the future, and projections of future commodities prices when making crop choice and pumping decisions. Our results therefore provide evidence that farmers recognize the nonrenewable nature of the resource that they manage, even though their property rights do not.

Strategic behavior in the face of spatial externalities

When farmers share the same aquifer with other farmers, a spatial externality arises whereby pumping by one user affects the extraction cost and total amount that is available to other nearby users. The spatial externality has been disaggregated into different types of effects, including a pumping cost externality and a stock or strategic externality (Negri, 1989; Provencher and Burt, 1993). The pumping cost externality arises because withdrawal by one user lowers the water table and increases the pumping cost for all users. The strategic externality arises because the property rights on the water in an aquifer are generally undefined. What a farmer does not withdraw today will be withdrawn by other farmers, which undermines their incentive to forgo current for future pumping (Negri, 1989). Theoretically, these externalities are potentially important causes of welfare loss (Dasgupta and Heal, 1979; Eswaran and Lewis, 1984; Negri, 1989; Provencher and Burt, 1993; Brozovic, Sunding and Zilberman, 2002; Rubio and Casino, 2003; Msangi, 2004; Saak and Peterson, 2007), but empirically we have little evidence to determine whether farmers react to these externalities or have an idea of their magnitude.

In Pfeiffer and Lin (2012), we investigate the behavior of farmers who share a common pool resource. We develop a spatial dynamic physical-economic model to characterize agricultural groundwater users' pumping behavior. We compare a social planner's optimal decisions with those of a group of profit maximizing individuals who have full property rights to the land, but whose groundwater is an incomplete common good because they cannot fully capture the groundwater beneath their land.

We then use data from western Kansas to econometrically determine if the pumping behavior of neighbors affects the groundwater extraction decision. The estimations are spatially explicit, taking advantage of detailed spatial data on groundwater pumping from the portion of western Kansas that overlies the High Plains Aquifer system.

Measuring interactions between neighbors is challenging because of simultaneity (individuals affect their neighbors and their neighbors simultaneously affect them) and spatial correlation in observable and unobservable characteristics (Manski, 1993; Glaeser, Sacerdote and Scheinkman, 1996; Brock and Durlauf, 2001; Moffitt, 2001; Conley and Topa, 2002; Robalino and Pfaff, 2012). The interaction of neighbors has been studied in oil extraction (Libecap and Wiggins, 1984; Lin, 2009). It has also been investigated in land use change using physical attributes of neighboring parcels as instruments to identify the effect of the behavior of neighbors on an individual (Irwin and Bockstael, 2002; Robalino and Pfaff, 2012).

We use an instrumental variables approach to purge neighbors' decisions of the endogenous component. Groundwater users in Kansas extract water under the doctrine of prior appropriation, meaning that they are allotted a maximum amount to extract each year. This annual amount was determined when the user originally applied for the permit. The permit amount for one's neighbors is a strong determinant of the actual pumping by one's neighbors, but is uncorrelated with one's own actual pumping, except through the effect of neighbors' pumping on one's own pumping. We therefore use the permit amount of one's neighbors as an instrument for neighbors' water pumping.

To take into account the way in which water moves through an aquifer, we weight our instrument by a function of the distance between each neighbor and the difference in lift height between neighbors that takes into account the way in which water moves through an aquifer. These weights adjust the amount pumped by the effect that it should have. If the distance between two wells is greater, the effect should be smaller. If the height gradient is larger, the effect should be greater.

This is the first study to empirically measure economic relationships between groundwater users. If externalities in groundwater use are significant, it lends insight into the causes of resource over-exploitation. If they are not significant or are very small in magnitude, a simpler model of groundwater user behavior, where each user essentially owns his own stock, is sufficient. Both outcomes would give guidance to policymakers, although it is important to note that the results are highly dependent on the hydrological conditions of the aquifer.

Details of our analysis are reported in Pfeiffer and Lin (2012). According to our results, we find evidence of a behavioral response to this movement in the agricultural region of western Kansas overlying the High Plains Aquifer. Spatial externalities resulting from the inability to completely capture the groundwater to which property rights are assigned cause some degree of over-extraction in theoretical models. Using an instrumental variable and spatial weight matrices to overcome estimation difficulties resulting from simultaneity and spatial correlation, we find that on average, the spatial externality causes over-extraction that accounts for about 2.5 percent of total pumping. Kansas farmers would apply 2.5 percent less water in the absence of spatial externalities (if, as an unrealistic example, each farmer had an impenetrable tank of water that held his or her portion of the aquifer).

Strengthening the evidence of the behavioral response to the spatial externalities caused by the movement of groundwater is the empirical result that when a farmer owns multiple wells, he does not respond to pumping at his own wells in the same manner as he responds to pumping at neighboring wells owned by others. In fact, the response to pumping at his own wells is to marginally decrease pumping, thus trading off the decrease in water levels between spatial areas and internalizing the externality that exists between his own wells.

Conclusion

In this chapter we discuss our research on several aspects of strategic behavior and regulation over time and space. The first aspect we discuss is the behavioral response to voluntary, incentive-based water conservation programs for irrigated agriculture. The second aspect of strategic behavior and regulation over time and space we discuss is how the prior appropriation doctrine affects dynamic optimality. The third aspect of strategic behavior and regulation over time and space we discuss is strategic behavior in the face of spatial externalities.

Strategic behavior and regulation over time and space can affect the optimality of the farmers' water extraction rate. Complete, measured, enforceable, and enforced property rights that consider the physical properties of the resource have the possibility of inducing the socially optimal rate of extraction in many cases. Where externalities occur, whether they are caused by the physical movement of water, by environmental damages or benefits, or by other causes, well thought-out policy can provide the incentives to move an individual's extraction path back to the socially optimal one. However, in practice, not all regulations over time and space induce the socially optimal rate of extraction.

Incentive-based groundwater conservation programs are a prime example of a well-intentioned policy that may have perverse consequences, for they may actually increase rather than decrease groundwater extraction. Similarly, property rights regimes such as prior appropriation may adversely impact the dynamic optimality of water extraction. When designing policies and regulation, policymakers need to be wary of any potential perverse consequences of their policies, and also be aware of the implications of their policies over time and space.

Notes

1 However, although irrigation was a large breakthrough, the non-irrigated regions to the east of the 100th meridian are larger and more productive (e.g., Iowa, Illinois, Indiana, Ohio, southern Missouri).

2 In the 2007 census, there were 65,531 farms in all of Kansas, of which approximately 29,039 were located in regions that roughly overlie the aquifer (USDA, 2011).

3 "Predevelopment" is defined as the water level in about 1960, when the first measurements were made.

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