The economics of sustainable agricultural groundwater management: Recent findings[1]

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Abstract

The sustainable management of groundwater resources for use in agriculture is a critical issue in California and globally. Many of the world's most productive agricultural basins depend on groundwater and have experienced declines in water table levels. The food consumers eat, the farmers who produce that food, and the local economies supporting that production are all affected by the availability of groundwater. Increasing competition for water from cities and environmental needs, as well as concerns about future climate variability and more frequent droughts, have caused policy-makers to look for ways to decrease the consumptive use of water. When designing groundwater management policies, it is important to consider any possible perverse consequences from the policy. In this paper, we discuss our research on the economics of sustainable agricultural groundwater management, including the possible perverse consequences of incentive-based agricultural groundwater conservation programs; the importance of dynamic management and spatial management; and the effects of climate change.

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1. Introduction

The sustainable management of groundwater resources for use in agriculture is a critical issue in California and globally. Many of the world's most productive agricultural basins depend on groundwater and have experienced declines in water table levels. The food consumers eat, the farmers who produce that food, and the local economies supporting that production are all affected by the availability of groundwater (Lin Lawell, 2016b). Approximately 25% of global crops are being grown in water-stressed areas (Siebert et al., 2013).

California is experiencing its third-worst drought in 106 years (Howitt and Lund, 2014). From 1960 to the present, there has been significant deterioration in the groundwater level of the Central Valley of California, making current levels of groundwater use unsustainable (Famiglietti, 2014). Groundwater management is particularly important in California as the state produces almost 70 percent of the nation's top 25 fruit, nut, and vegetable crops (Howitt and Lund, 2014).

Most crops in California come from two areas: the Central Valley, including the Sacramento and San Joaquin valleys; and the coastal region, including the Salinas Valley, often known as America's "salad bowl". Farmers in both areas rely heavily on groundwater, especially during periods of drought when traditional surface water sources, including dams and reservoirs, face shortages (York and Sumner, 2015). For example, during the recent drought, most farmers did not use water from the Central Valley Project, a network of dams, reservoirs, and canals; and surface sources in the Salinas Valley, including Lake San Antonio, fell to 5 percent of their storage capacity (York and Sumner, 2015).

Understanding the economics of sustainable agricultural groundwater management is particularly timely and important for California as legislation allowing regulation of groundwater is being implemented gradually in California over the next several years (York and Sumner, 2015).

When designing groundwater management policies, it is important to consider any possible perverse consequences from the policy. In this paper, we discuss our research on the economics of sustainable agricultural groundwater management, including the possible perverse consequences of incentive-based agricultural groundwater conservation programs; the importance of dynamic management and spatial management; and the effects of climate change.

2. Perverse Incentives From Policy

Incentive-based water conservation programs are extremely popular policies for water management. Farmers can receive a subsidy for upgrading their irrigation systems; less groundwater is "wasted" through runoff, evaporation, or drift; marginal lands can be profitably retired; and farmers can choose whether to participate. However, as our research demonstrates, such policies can have perverse consequences (Pfeiffer and Lin, 2010; Lin, 2013; Pfeiffer and Lin, 2014a; Pfeiffer and Lin, 2014b).

In many places, policy-makers have attempted to decrease rates of groundwater extraction through incentive-based water conservation programs. In California, the State Water Efficiency and Enhancement Program (SWEEP) provides financial assistance in the form of grants to implement irrigation systems that reduce greenhouse gases and save water on California agricultural operations, including evapotranspiration-based irrigation scheduling to optimize water efficiency for crops; and micro-irrigation or drip systems (California DWR and CFDA, 2017). San Luis Canal Company in the San Joaquin Valley offers $250 per acre to "encourage the transition to pressurized irrigation systems among other actions" (CEC, 2015a).

Similarly, though funding for this order was not passed, under the Water and Energy Saving Technologies Executive Order B-29-15, the California Energy Commission, Department of Water Resources, and State Water Resources Control board were to provide funding for innovative technologies, including rebates for conversion from high pressure to low-pressure drip irrigation systems (CEC, 2015b).

However, although they are extremely popular policies for water management, 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 (Pfeiffer and Lin, 2014a; Lin Lawell, 2016b).

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. 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 program, which does not have any effect on the amount of irrigation water extracted (Pfeiffer and Lin, 2014a; Lin Lawell, 2016b).

In our study (Pfeiffer and Lin, 2014a), which has been featured in such media outlets as the New York Times (Wines, 2013), the Washington Post (Howitt and Lund, 2014), Bloomberg View (Ferraro, 2016), and AgMag Blog (Cox, 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. Similarly, we find essentially no effect of land conservation programs on groundwater pumping, since farmers may opt to enroll non-irrigated plots instead (Pfeiffer and Lin, 2014a; Lin Lawell, 2016b).

Our result that increases in irrigation efficiency may increase water consumption is an example of a rebound effect, or "Jevons' Paradox", which arises when the invention of a technology that enhances the efficiency of using a natural resource does not necessarily lead to less consumption of that resource (Jevons, 1865). In the case of agricultural groundwater, we find that irrigation technology that increases irrigation efficiency does not necessarily lead to less consumption of groundwater (Lin, 2013; Lin Lawell, 2016b). In particular, if demand is elastic enough, the higher efficiency technology operates at a lower marginal cost, and the higher efficiency technology increases revenue, then irrigation efficiency will increase applied water (Pfeiffer and Lin, 2014a; Lin Lawell, 2016b). Indeed, field experimental evidence suggests that farmers respond elastically to price signals related to groundwater extraction, such as electricity prices (Foster, Rapaport and Dinar, 2016).

In California, SWEEP grant funds cannot be used to expand existing agricultural operations or to convert additional new acreage to farmland (California DWR and CFDA, 2017), which may limit how much a farmer can respond to the increased irrigation efficiency resulting from SWEEP grant funds to increase irrigated acreage. However, by lowering the marginal cost of irrigation, SWEEP grant funds may encourage farmers to continue irrigating more marginal lands. Furthermore, this increased efficiency may allow farmers to continue growing more water intensive crops, even as groundwater becomes scarcer. Thus, SWEEP funds could make farmers in water-stressed locations less sensitive to existing price signals as groundwater becomes scarce, thereby slowing their adjustment to depleting groundwater stocks over the long term.

The California Department of Agriculture and the California Department of Water recently introduced a pilot program within SWEEP that incentivizes joint action by farmers and larger water suppliers to implement more efficient irrigation technology in return for an agreement to halt the use of groundwater for agricultural purposes (California DWR and CFDA, 2016). However, this program may be used most by farmers and water suppliers who rely relatively little on groundwater as a source. In this case, while irrigation may become more efficient, this may have little effect on groundwater use, the target of the policy. As a result, the costs of the program may unfortunately exceed its benefits.

While heavily irrigated, California's cropland still includes almost one million acres of dry land farming, or non-irrigated land used for planting crops. Dry land farming constitutes about 9 percent of total cropland and 3.5 percent of total farmland in California. Another half a million acres of cropland is currently left to pasture, but could be converted to cropland without improvements. In addition, farmland in California includes about 13 million acres of rangeland and pasture, only about half a million of which is irrigated (USDA, 2012). Thus, a possible perverse consequence of California's SWEEP grant funds is that farmers have may choose to convert more marginal land that is currently used for rangeland and dry land farming to more productive irrigated cropland as part of any efficiency gains from new irrigation technology purchased with state incentives, and this possible increase in irrigated acreage may lead to an increase in groundwater consumption. Furthermore, cultivation of marginal land often requires excessive use of chemicals, and can damage other nearby water sources (Myers and Kent, 1998; Sinclair, 1987).

Land retirement programs at the federal and state level have had limited effectiveness in California, and may also have perverse consequences. The largest federal land retirement program, the Conservation Reserve Program, provides rental payments to landowners who retire their land and follow conservation practices for a contracted period of time, usually 10 years. While this program has retired 35 million acres of land nationally, it had only enrolled about 138,000 acres in California as of 2007, well below its share in total farmed acres (Champetier de Ribes and Sumner, 2007). This is due in large part to the relatively high value of agricultural land, particularly irrigated farmland, in California.

The most important state-level land retirement program in California is the Central Valley Project Improvement Act Land Retirement Program, which purchases land and water rights from owners (Land Retirement Technical Committee, 1999). Between 1992-2011, the program has retired about 9,000 acres as part of a planned 100,000 acre retirement (California DWR, 2016).

The modest effect of land retirement programs on groundwater extraction in California is evidence of a design flaw of land retirement programs. In areas of high value agricultural production like California, farmers will demand much higher payments to voluntarily abandon crop production. Since California's most water-stressed regions coincide with areas of high value irrigated agricultural production, land retirement programs in these areas may be limited in their effectiveness, or very costly. In addition, the relatively low levels of Conservation Reserve Program spending in California suggest that the land that has been enrolled in the program is likely low-value land. Thus, just as in Kansas, land conservation programs may be ineffective in reducing groundwater extraction in California.

3. Dynamic Management

If an aquifer receives very little recharge, then it is least partially a nonrenewable resource and therefore should be managed dynamically (Lin Lawell, 2016a). The idea behind dynamic management is that water managers need to account for the future when making current decisions. In particular, water managers may wish to extract less groundwater today in order to save more for tomorrow (Gisser and Sanchez, 1980; Feinerman and Knapp, 1983). Dynamic management is particularly important if an aquifer receives very little recharge, since in this case it is least partially a nonrenewable resource (Lin Lawell, 2016a).

There are two main reasons why groundwater needs to be managed dynamically, particularly if the aquifer receives very little recharge. First, groundwater extraction today decreases the amount of groundwater available tomorrow. Second, groundwater extraction today increases the cost of extraction tomorrow because removal of water today increases the "lift-height" needed to lift the remaining stock to the surface tomorrow, thereby increasing the pumping cost. Thus, because the extraction of groundwater both decreases the future amount of groundwater available and increases the future cost of extracting groundwater, sustainable agricultural groundwater extraction may entail extracting less groundwater today in order to avoid future supply shocks.

Dynamic management may be important in California, where recharge rates are low. Comparing aquifer systems found in irrigated agricultural regions in the U.S., aquifers in the Central Valley have recharge rates of between 420-580 mm per year, which is within the range found in the High Plains, an aquifer which receives little recharge (Lin Lawell, 2016a); is higher than recharge rates in the Pacific Northwest; and is lower than recharge rates in the Aluvium aquifer system (McMahon et al., 2011). Thus, groundwater in California is at least partially a nonrenewable resource and therefore should be managed dynamically.

4. Spatial Management

In addition to dynamic considerations, sustainable agricultural groundwater management needs to account for spatial considerations as well. Spatial considerations arise because groundwater users face a common pool resource problem: because farmers are sharing the aquifer with other farmers, other farmers' pumping affects their extraction cost and the amount of water they have available to pump. Consequently, groundwater pumping by one user raises the extraction cost and lowers the total amount that is available to other nearby users (Pfeiffer and Lin, 2012; Lin and Pfeiffer, 2015; Lin Lawell, 2016b). These spatial externalities can lead to over-extraction.

In our research (Pfeiffer and Lin, 2012), we empirically examine whether the amount of water one farmer extracts depends on how much water his neighbor extracts. Our econometric model is spatially explicit, taking advantage of detailed spatial data on groundwater pumping from the portion of western Kansas that overlies the High Plains Aquifer system, and enables us to isolate the effects of neighbors' pumping on a farmer's own pumping decision. Unlike previous studies of spatial implications (e.g., Suter et al., 2012), our study is the first study to empirically measure economic relationships between groundwater users using observational data. We find that on average, Kansas farmers would apply 2.5 percent less water in the absence of spatial externalities (Pfeiffer and Lin, 2012; Pfeiffer and Lin, 2015; Lin Lawell, 2016b).

In Sears, Lim and Lin Lawell (2017), we discuss spatial groundwater management in California. Groundwater managers each managing a subset of the plots of land over an aquifer and each behaving non-cooperatively with respect to other groundwater managers will over-extract water relative to the socially optimal coordinated solution if there is spatial movement of water between patches that are managed by different groundwater managers. Thus, in order to achieve the socially optimal coordinated solution, the jurisdictions of local agencies should be large enough to internalize all externalities, so that there are no transboundary issues between jurisdictions. This means that local agencies should each cover an entire groundwater basin, and also that a groundwater basin should not be managed by multiple Groundwater Sustainability Agencies (Sears, Lim and Lin Lawell, 2017).

According to our analysis, however, we find that although California's 2014 Sustainable Groundwater Management Act and 2015 Strategic Plan for implementing it may have specified the efficient allocation of regulatory responsibility between central and local tiers of government, the jurisdictions for the local agencies do not internalize all the spatial externalities. As a consequence, the local agencies may behave non-cooperatively, leading to over-extraction relative to the socially optimal coordinated solution (Sears, Lim and Lin Lawell, 2017).

5. Climate Change

Climate change has the potential to impact groundwater availability in several ways. First, climate change may cause changes in agricultural land use and changes in agricultural practices that then result in changes in groundwater extraction. Second, changes in climate may result in melting snowcaps and/or changes in precipitation which would affect the availability of water for agriculture (Bertone Oehninger, Lin Lawell and Springborn, 2017a).

In California, climate change is already impacting California's water resources (California Department of Water Resources, 2007). The California Department of Water Resources anticipates that warmer temperatures, different patterns of precipitation and runoff, and rising sea levels will profoundly affect the ability to manage water supplies in California; and cites the adaptation of California's water management systems to climate change as "one of the most significant challenges for the 21st century" (California Department of Water Resources, 2007).

In Bertone Oehninger, Lin Lawell and Springborn (2017a), we analyze the effects of changes in temperature, precipitation, and humidity on groundwater extraction for agriculture. We find that changes in climate variables influence crop selection decisions, crop acreage allocation decisions, technology adoption, and the demand for water by farmers. In Bertone Oehninger, Lin Lawell and Springborn (2017b), we find that such changes in behavior could affect land use and agricultural variety.

6. Conclusion

Sustainable agricultural groundwater management policies need to account for dynamic and spatial considerations that arise with groundwater, as well as for any possible perverse consequences from the policy.

Incentive-based groundwater conservation programs are a prime example of a well-intentioned policy that may have perverse consequences, meaning that they may actually increase rather than decrease groundwater extraction. Irrigation efficiency incentives may actually lead to an increase in groundwater use by lowering the marginal cost of irrigation, and by making marginal land cheaper to irrigate. On the other hand, land retirement programs may prove ineffective since they incentivize the farmer to retire his or her least productive, and thus least likely to be irrigated, land. Thus, when designing policies and regulation, policy-makers need to be aware of the full range of implications of their policy, including any potential perverse consequences.

Our research on the economics of sustainable agricultural groundwater management – including the possible perverse consequences of incentive-based agricultural groundwater conservation programs; the importance of dynamic management and spatial management; and the effects of climate change – has important implications for the design of policies for sustainable agricultural groundwater management for California and globally.

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