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Economic impacts on irrigated agriculture of water conservation programs in drought

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SUMMARY

The need to adapt irrigation patterns to water shortages in the world's dry regions continues to inspire economically attractive measures to sustain food security and improve farm incomes. Ongoing evidence of climate variability and growing populations amplify the importance of this search. Motivated by recent severe drought in the southwestern United States, this study analyzes vulnerability, impacts, and adaptability by irrigation technology in a sub-basin of North America's Rio Grande. The study accounts for economic incentives affecting choices on irrigation technology, crop mix, and water source in the face of water conservation subsidies under various levels of surface water shortage. Findings show that when surface water supplies are reduced, farmers shift to aquifer pumping even when pumping raises the cost of production or reduces yield. An important on-farm drought adaptation mechanism comes by converting from surface irrigation to water conserving irrigation technologies when faced with lower financial costs for conversion. Public subsidies to convert from flood to drip irrigation offset many of the negative impacts of drought on farm income. These subsidies also raise the value of food production, reduce the amount of water applied to crops, but can increase crop water depletions. Our approach for analyzing drought adaptation impacts and adjustment mechanisms can be applied where water shortages loom, food security is important, and water conservation policies are under debate. Results provide insights for the design of adaptation mechanisms for the world's dry regions for which policymakers need to reduce economic damages from future climate variability and change.

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1. Background

Growing populations worldwide, rising international needs for food security, climate change, and increased economic values of water inside and outside irrigated agriculture continue to challenge policy making in both developed and developing communities. These problems challenge the sustainability of economic growth, viability of key ecological assets, and welfare of the poor who bear a large part of the costs of water shortages that could face irrigated agriculture, the world's largest water user. Moreover, by conventional economic valuation standards, irrigated agriculture can produce low economic values of water at the margin compared to uses of water by competing sectors.

The southwestern United States, a very dry place in normal periods, occupies the front lines of challenges faced by the need to adapt to recurrent drought. This drought has been even more severe since 2010. In New Mexico, for example, much of current water planning and policy is based on a historical trend of 6–10 in. precipitation per year. Among other things, it faces international treaty water delivery obligations, federal requirements for endangered species protection, interstate compact delivery obligations, and several water allocation challenges within its borders. When the historical 6–10 in. fail to arrive in a given year, water users suffer cutbacks, with an especially heavy burden shouldered by irrigated agriculture. When the rains fail to arrive for two or more years, rivers, reservoirs, and aquifers face increased pressure of the kind seen in 2010–2013. Examples from 2013 include:

- Irrigation farmers accustomed to 3 acre-feet of surface irrigation water receive 3 in.
- Pecan growers in the Mesilla Valley prune trees to the trunk to make them last.
- Water levels at Elephant Butte Reservoir fall to historic lows.
- Texas sues New Mexico over water shortages in the Mesilla Valley.
- Farmers turn to groundwater pumping to make up for lost river water.

These events have occurred after three very dry years. Water planners are asking what can be done if decades pass before the historical 6- to 10-in. levels of precipitation is restored. What is the best way for water users to adapt to the new normal? Water right ownership brings no wet water. With growing concerns

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about the viability of irrigated agriculture in the drier parts of the US in addition to similar concerns worldwide in the face of recurrent and severe droughts there is a need to find measures to inform policy and management debates on sustainability of agricultural production while responding to rising water scarcity in the face of recurrent drought.

Faced by growing water demands and increased climate variability, recent years have seen much attention on drought scenarios and drought adaptation measures. As a natural hazard, drought can be characterized by several climatological and hydrological indices. A good understanding of the relations between both kinds of indices is needed to establish informed plans to adapt to and mitigate impacts of drought. A recent exhaustive review article in this *Journal* by Mishra and Singh (2010) integrates concepts of drought, drought classification, drought indices, historical droughts viewed by paleo-climatic studies, and the relation between droughts and selected climate indices.

Challenges posed by irrigators who need to adapt to recurrent or severe drought is an ancient problem. But it has seen comparatively little systematic or scholarly work until the late 20th century. Several papers since the early 1990s touched on its various dimensions. An early study from the 1990s found that price-based regulation may not produce water conservation and it also found that conservation policy instruments should be chosen for their capacity to achieve the purposes of water conservation policy (Moore, 1991). Similar work from the US Pacific Northwest found that in the absence of water policy changes in the US, continued irrigation technology adoption could result in an annual water savings of approximately 404,000 acre-feet (Schaible et al., 1991). An early innovative study reviewed the influence of groundwater pumping by irrigators on surface returns to the river system (Suso and Llamas, 1993) extending findings of much earlier studies from the early 1940s. Another work conducted to address issues in developing countries found that where surface water is scarce, drip irrigation can conserve water applications, but its cost of $1000 an acre is prohibitive for most small farmers in developing countries (Polak et al., 1997). Michelsen and his collaborators in 1999 examined the meaning of water conservation found that the term is slippery and hard to define with precision (Michelsen et al., 1999).

Water pricing and marketing measures were found to be an effective resource management measure to promote water conservation (Schuck and Green, 2001) by encouraging reductions in crop water consumption (crop ET). Some early modeling work attempted to identify factors that would promote water conservation in crop irrigation at the basin scale (Cai et al., 2002, 2003).

Later empirical findings suggested that when traditional water conservation technologies are used by farmers, optimization over the entire basin leads to increases in aggregate output when switching from traditional to modern irrigation technology (Chakravorty and Umetsu, 2003). Using several irrigation districts in northern China, analysis found that pricing policies brought little to no water conserved in irrigation under China's current water institutions (Yang et al., 2003). Statistical analyses of water transfers in the Lower Orange River in South Africa showed that only unused water rights were transferred to new uses, while water saved through adoption of conservation practices was retained in the location of origin for security purposes (Nieuwoudt and Armitage, 2004).

More recent modeling work analyzed effects of water costs to find the optimum strategy for farm income maximization, based on its main determining factors such as irrigation system, climate variability, and the like (Ortega et al., 2004). Findings from a study in Colorado and Kansas found that price incentives are likely to have limited impacts on basin-wide water consumption and would make little additional water available for emerging demands (Scheierling et al., 2004; Peterson and Ding, 2005). A similar paper explored the role of economic valuation techniques to inform the design of efficient, equitable and sustainable policies for water resources management in the face of environmental challenges like water pollution (Birol et al., 2006).

Loss of groundwater through increased evapotranspiration (ET) has been reported extensively in the hydrological literature. A 2006 study found that this ET loss could be reduced by a pumping well that reduces the water table within the cone of depression, in spite of the fact that the hydrograph's characteristics affect the proportion of water storage volume returning to the aquifer (Chen and Shu, 2006; Mudd, 2006). By contrast a recent economic analysis found that the price elasticity of agricultural water demand is −0.79, larger in absolute terms than that found in previous studies (Schoengold et al., 2006). Ongoing pressure to develop some of Australia's dryland river basins for irrigation has been reduced with increasing ecological degradation. Work there explored the importance of local and catchment rainfall in contributing to floods (Young et al., 2006).

Pumping in the Ogallala Aquifer of the US state of Kansas has occurred due to expansion of irrigated agriculture. Using a linear programming model, innovative work conducted in that region used a production frontier approach seeking crop irrigation patterns using the least amount of water (Lilienfeld and Asmild, 2007). A study from Tibet integrated a hydrologic and economic analysis that approximated the supply response of conserved water for both irrigated and rain fed crops (Immerzeel et al., 2008).

A 2008 study on the Lower Jordan River Basin found that prices are unlikely to limit groundwater pumping and significant reduction will only be achieved through policies that reduce the number of wells in use, such as regulating or buying existing wells (Venot and Molle, 2008). A study on the Rio Grande Basin of North America found that policies aimed at reducing water applications in irrigated agriculture can actually increase water depletions. Achieving real water savings was found to require designing institutional, technical, and accounting measures that accurately track and economically reward reduced water depletions (Ward and Pulido-Velazquez, 2008; Nixon, 2013). A 2009 study China describes the growth and importance of irrigation in China in terms of the expansion of surface water irrigation led by the state, and the more recent acceleration of groundwater irrigation led by individual farmers (Calow et al., 2009). Results from a 2010 analysis in Iran showed that 88% of added wheat production demands will need to be produced in its water scarce provinces (Faramarzi et al., 2010).

Work from the Murray Darling Basin of Australia made an empirical comparison of two incentive policies to acquire water for environmental flows for the Basin. The first option results in larger return flow reduction, while the second leads to significant irrigated land retirement (Qureshi et al., 2010). A recent study from India found that long-term success of irrigated agriculture for sustainable crop production in that country depends on the careful management of land and water resources (Singh, 2010). Hydrogeological work conducted for the US High Plains Ogallala Aquifer found that the fragmented and piecemeal institutional arrangements for managing water are inadequate to meet the water challenges of the future (Sophocleous, 2010). Work conducted in China found that less government interference in the implementation of water conserving policy instruments and institutions is likely to enhance both ecological and economic benefits (Qu et al., 2011). Another work from China examined the problem of groundwater overdraft as it threatens the future of irrigated agriculture in the North China Plain. Widespread implementation of measures that reduce depth of irrigation water applied (regulated deficit irrigation) could produce a significant water savings with an economic benefit if managed carefully (Zhang et al., 2011). Work from Iran found that an irrigation conservation subsidy policy is likely to incur a high cost to the

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