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Upstream with a shovel or downstream with a water right? Irrigation in a changing climate

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ABSTRACT

Irrigation of crops is responsible for 40 percent of the world's food supply. A ubiquitous issue in irrigation is the tendency of upstream users to deplete the stream and deprive downstream users of water. Climate change threatens to exacerbate this problem by threatening the water supply to many irrigation systems, especially those that rely on snowmelt. Using a natural experiment in the Rio Grande Basin of Colorado, I examine five hypotheses about how water rights and physical properties of irrigation systems interact to produce varying levels of irrigation performance. Results indicate that enforced water rights are reliably influential, but their influence depends on diversion location, geographic features of the watershed, physical water availability, and higher level water policy. Results highlight the interdependence of institutions and geography and support a role for carefully crafted water rights congruent with cultural norms and higher level policy in adaptation to climate change.

1. Introduction

1.1. Study summary

One of the major challenges facing water management around the globe is the interaction between upstream and downstream water users. In theory, water rights should be an effective way to mitigate the "stationary bandit" behavior of upstream users (Janssen et al., 2011). But are they in practice? And to what degree does climate change influence upstream-downstream relationships when water rights are involved? To address these questions, this study looks at irrigation performance in the Rio Grande Basin in Colorado, commonly referred to as the San Luis Valley (SLV), where snowmelt dependent irrigation is the dominant economic activity. Like other regions of the world, the SLV hosts informally and formally enforced water rights, multiple watersheds with differing physical, cultural, and policy environments, and hundreds of irrigation systems with a wide range of attributes. Importantly, the SLV has ample public data on geography, hydrology, climate, and irrigation systems, offering a chance to control for effects that might be difficult to engage elsewhere.

At a minimum, an irrigation system is defined as the physical infrastructure used to capture, divert, and deliver water to the fields of irrigated farmers (Ostrom, 1992). In studies of irrigation systems, the users of the system as well as the lands irrigated by the system are also covered by the phrase "irrigation system" (Ostrom, 1992; Lam, 1998; Cox and Ross, 2011). To say that these irrigation systems are user-governed means that farmers themselves maintain and manage the distribution of water through the headgates, canals, and ditches (Mabry, 1996). Irrigation performance in this study is measured at the level of the irrigation system (not individual farmers), and is assessed by three metrics for each year of the study period (1984–2015): the percentage of irrigable land irrigated by a given system, the percentage of the maximum volume of water diverted by a given system over the study period, and the number of calendar months over the calendar year during which water was diverted by a given system. See Section 2.1 of the Supplementary material for more information on irrigation performance.

Irrigation performance is important for global food security, a growing problem that will be made worse as the climate changes and demands on water resources grow (Castex et al., 2015; Cox, 2014; Fernald et al., 2012; Hurlbert and Mussetta, 2016; Wheeler and von Braun, 2013). Irrigation of crops is responsible for 40 percent of the world's food supply and is expected to provide most new food (UN IFAD, 2016). Climate change threatens the water supply to many irrigation systems (FAO, 2012; Gleick, 2003), and therefore global food security. Because approximately three quarters of irrigated cropland and one quarter of all cropland relies on small-scale, user-governed irrigation systems worldwide (Mabry, 1996), adaptation will be performed primarily by farmers. In this context, user-governed irrigation systems' adaptations result in varying irrigation performance (Cox and Ross, 2011; Janssen and Anderies, 2013). Performance depends on the interactions between geography, technology, and institutions (Ostrom,

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1992; Poteete et al., 2010; Hansen et al., 2011).

One way that irrigators might be able to adapt to climate change is through the adoption and adaptation of property rights to water (Meinzen-Dick, 2014; Gupta and Lebel, 2010). Research on human behavior indicates that both moral and economic incentives can influence collective action (Ostrom, 2005). Institutions such as water rights provide both economic and moral information to water users, and therefore institutions should be influential in determining irrigation performance because of their capacity to reveal information about the potential economic and social outcomes of alternate decisions. While the water rights regime in Colorado – Prior Appropriation (PA) – is unique to the Western US, some portions of Canada, and Australia, the ultimate effect of the regime is to create a “priority system” where irrigators are ranked based on a rule of “first capture” (Kenney, 2005; Libecap, 2011) and higher ranking “senior” users may take water prior to and for longer periods than “junior” users, who sometimes receive no surface water at all. Property rights in the United States generally and water rights in Colorado especially are strongly enforced by the court system, and so one would expect property rights to water to dominate irrigation in the SLV and in other contexts of strong enforcement.

However, there is a tongue-in-cheek saying in the SLV: “It’s better to be upstream with a shovel than downstream with a water right.” The aphorism highlights the importance of being able to divert water before other irrigators and thus deprive them of water. Similarly, in an extensive study of irrigation performance in Nepal, Lam (1998) finds that on irrigation systems themselves, upstream users (“head-enders”) tended to access water more reliably than downstream users (“tail-enders”). At a larger scale, downstream nations (e.g. Mexico, Egypt, Vietnam) also often find themselves in less powerful positions relative to their upstream counterparts (The United States, Ethiopia and Sudan, China, respectively). Between US states, many lawsuits brought between states over water involve the downstream state suing the upstream state for allegedly taking more than its fair share (e.g. *Texas v. New Mexico and Colorado*; *Florida v. Georgia*; *Mississippi v. Tennessee*). Experiments find that upstream users act as “stationary bandits”, depriving downstream users of water (Janssen et al., 2011).

That said, in a snowmelt driven system, being too far upstream is hypothetically possible. If diverting from a tributary rather than a mainstem, fewer streams aggregate and therefore reduce the reliability of flow (Xu et al., 2014b). And if catchment sizes are smaller, less water is available (USDA, 2012). There are instances in Colorado where upstream users have senior rights but are not able to divert water because it simply is not there (denoted as a “futile call”). Therefore, the hydrograph of the stream from which water is diverted (USDA, 2012; Xu et al., 2014b), the number of irrigators diverting water upstream of a given user (Janssen et al., 2011; Lam, 1998), and available storage technology (Cody et al., 2015; Cox and Ross, 2011; Smith, 2016) combine to influence physical water availability and therefore the relative role of water rights.

The literature has not come to agreement on the question of whether water rights or geography have more influence on irrigation performance and why that might be (Poteete et al., 2010).

Here I look at the effect of water rights and position on the stream, controlling for important variables such as elevation, across a variety of watersheds where conditions are likely to be different in important ways (Alcon et al., 2014). This analysis can inform the kinds of institutional interventions or support, if any, might be needed to adapt to a dryer climate and the some of the important contextual factors that could be involved (Mukhtarov et al., 2015). At a minimum, it will illuminate the extent to which water rights may be a lever of adaptation to drought.

I evaluate five hypotheses, shown in Table 1. In general, I would expect these hypotheses to be true in any snowmelt dependent irrigation context, with the caveat that it is possible some factors – such as treaties and cultural norms – could create situations where these hypotheses do not hold. These hypotheses are evaluated for the period 1984–2015 on a completely sampled population of 696 irrigation systems, drawing on publically available data collected from the State of Colorado and the US Geological Survey. To ensure the sample has comparable observations, I use genetic matching procedures (Diamond and Sekhon, 2013; Ho et al., 2007) to produce a final dataset of 402 irrigation systems. Because the variables of interest, water right priority and geographic factors, are time-invariant making fixed-effects analysis impossible, the time-variant data associated with each observation are averaged over the study period. To ease interpretation of results, the data are then standardized (variables are centered at their means, then divided by the variable’s standard deviation) except for the dichotomous and categorical variables. Regression analyses are then performed on this standardized cross sectional data following Gujarati and Porter (2009). Quantitative data and results are complimented by field visits over the period of 2012–2016. The methods section below elaborates this approach, and further details are contained in Section 2.2–2.3 of the Supplementary materials.

Results indicate that while water right priority rank has a significantly positive effect for all dependent variables, its influence depends on several factors, including catchment area, whether the system diverts from a tributary, available precipitation, and number of upstream diversions. Overall, increasing catchment area is as influential as water right priority rank. Other signals are not as strong. Diverting from a tributary is significantly harmful for percent maximum volume diverted and percent area irrigated, but not months of active diversion. Many upstream diversions is only significantly harmful for percent maximum volume diverted. Finally, PA created stark inequalities among irrigators in the extreme 2002 drought, especially among those lacking storage, with senior users receiving their full allocation of water (albeit for a shorter period than normal) and junior users receiving no water. In a context without savings, insurance, credit, and/or access to secondary sources of income or food, PA could generate significant social discord, potentially leading to hunger, migration, and/or physical conflict.

1.2. Theoretical approach

The Institutional Analysis and Development (IAD) framework (Poteete et al., 2010) is useful for examining the question of how the institutional and physical dimensions of a Social-Ecological System (SES) interact to influence irrigation performance. In addition to being designed to analyze institutions, the IAD framework has well defined and clearly separated variable concepts and easily accommodates different theories (Sabatier, 2007). The IAD framework separates contextual variables into three categories: Biophysical, Institutional, and Socio-Economic (i.e. “attributes of the community”). These contextual variables influence actors who make decisions in an “Action Arena”, which produce outcomes that feedback on the contextual variables. Furthermore, related scholarship (Cox and Ross, 2011; Cox, 2014; Smith, 2016) uses the IAD framework as a basis for investigations into similar questions in geographically proximate and institutionally similar systems. This study complements this work using similar methods. Fig. 1 illustrates a highly simplified version of the IAD framework and where the variables under consideration fit into it. Fig. 1 is more applicable to my specific research problem because it locates the variables in physical space. Although there are feedbacks over time in any SES, Fig. 1 omits them because the variables under consideration here are largely unresponsive to these feedbacks over the study period because they are either legally, financially, or physically limited.

Closely related to the IAD framework is CPR theory (Ostrom, 2005), which posits that human users of CPRs can act collectively to create institutions which evolve over time to manage their use of said CPRs and that long-lived commons management regimes share essential features related to the evolution of cooperation (Wilson et al., 2013). Irrigation systems, like all CPRs, face problems with difficulty of exclusion (access to the resource is difficult to restrict) and subtractability

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