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The Economics of Drought

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Abstract

Water scarcity and drought have determined the structure, location, and fate of civilizations throughout history. Drought remains an important factor in the performance of developed and developing economies, especially in the agricultural sector. While significant attention has been paid to drought as a meteorological phenomenon and on its economic impact, comparative institutional analysis of the economics of drought is limited. In this review, we focus on how economic institutions, the humanly devised constraints that shape the allocation and use of water, impact the severity and incidence of droughts. Water property rights in developed countries encourage infrastructure investments and reallocations that mitigate drought impacts, although such institutions may codify inequitable water access during drought. Developing economies rely more on informal strategies for mitigating drought and remain more vulnerable, experiencing economic losses, conflict, and violence.

1. INTRODUCTION

Droughts occur when an area experiences anomalously low rainfall and acute water scarcity emerges. Catastrophic drought was responsible for the rapid collapse of ancient civilizations: a 30% decline in precipitation over 100 years around 2,200 BC for the Akkadian empire (Cullen et al. 2000), a 50% decline for the Maya around 800–1,000 CE (Evans et al. 2018), and two droughts with 40% reductions in precipitation around 1,150 and 1,300 CE for the Anasazi (Benson et al. 2007). Today, as many as four billion people experience severe water stress for at least part of the year (Mekonnen & Hoekstra 2016).

More than 85% of the population affected by dry shocks live in low- or middle-income countries (Damania et al. 2017). In these regions, moderate drought reduces gross domestic product (GDP) growth by about 0.39 percentage points and extreme drought by about 0.85 percentage points, relative to an average growth rate of 2.19% (Zaveri et al. 2023). Severe drought's effect on growth in developed economies is much smaller. A partial explanation for the economic importance of drought in developing countries is their high agricultural share of GDP. Across developed and developing economies, water is predominately used in agriculture. Consumptive water use in agriculture exceeds 85% of the worldwide total (D'Odorico et al. 2020). Agricultural productivity is highly sensitive to rainfall shocks, with net primary productivity—the amount of carbon stored for food consumption per square meter of crop—decreasing by up to 14% during even moderate droughts (Damania et al. 2017).

In principle, water can be moved across space and stored over time to mitigate drought impacts. The ancient civilizations cited above all had the infrastructure to move water for irrigation, sometimes over great distances. The shared nature of water resources and the economies of scale associated with moving and storing water for agriculture require coordination. These drought-related organizational structures can be complex and robust enough to form a foundation of government (Allen et al. 2023). In part because drought preparation and response are collective endeavors, drought outcomes across and within countries are divergent. Adverse consequences of drought can include violence (Koren et al. 2021), famine (Mishra et al. 2019, Njoka 2019), and migration (Hornbeck 2023), but they do not always occur.

In this review, we explore how economic institutions, the humanly devised constraints that shape the allocation and use of water, mediate drought outcomes. Poorly functioning institutions lead to more serious drought shocks and broader effects on the economy and society, consistent with the divergence in drought outcomes observed in developing relative to developed countries. Developing economies often have weak institutions, incomplete markets, and deficiencies in water infrastructure. Because institutions are inadequate, the impacts of droughts can be more severe, and informal and social drought responses can play a more important role. We propose a unifying framework for understanding the outcomes of drought by answering three questions related to the institutional arrangements around water:

1. Allocation: Who gets water during drought?
2. Infrastructure: What technologies and investments are available to mitigate drought?
3. Markets: How flexibly do the economy and individuals allocate water and other goods and services in response to drought?

We begin in Section 2 with a broad discussion of drought and its economic consequences. We then introduce an economic framework for understanding water scarcity and the role of institutions in Section 3. Section 4 discusses the role of water property right systems in allocating water during drought and the reallocation of water via formal and informal markets. Section 5 provides concrete examples of how institutions evolve in response to droughts, while Section 6 addresses inequity in these institutions. Section 7 concludes with a discussion, briefly highlighting identifiable areas of further inquiry.

2. CAUSES AND CONSEQUENCES OF DROUGHTS

2.1. Drought and Climate Change

Defining a drought is fundamentally related to both economic and environmental conditions. Many arid and semiarid regions are characterized by frequent drought, and there is no clear distinction between institutions that manage water allocations every year and those that manage water during drought. The distinction becomes particularly difficult when infrastructure (e.g., dams) or natural capital (e.g., groundwater aquifers) allow stored water to smooth drought impacts. Thus, while the focus of this article is on the acute effects of drought, many of the topics relate more broadly to the institutions that manage water scarcity.

Formal definitions of drought include meteorological drought, defined by below-normal rainfall; agricultural drought, where dry soil fails to support plant growth (quantified through measures like the Palmer Drought Severity Index); hydrological drought, which reflects declines in surface or groundwater availability; and socioeconomic drought, which occurs when one of the other three types of drought affects social and economic systems (Fleming-Muñoz et al. 2023). Meteorological drought is a relative measure, so drought in the Amazon could equate to a deluge if that rainfall occurred in the typically arid southwestern United States. The other three drought definitions are affected by existing water institutions and local characteristics of demand.

Between 1970 and the early 2000s, the percentage of the Earth's land area under serious drought more than doubled (Dai et al. 2004). Drought risk is expected to increase in Central Europe, South-Central Asia, South America, and the southeast United States—some of the planet's most highly populated and agriculturally productive areas (Carrão et al. 2016, Dai 2011). The expansion of drought conditions around the subtropics is largely due to the effects of climate change on global precipitation patterns (Carrão et al. 2016). Rising global temperatures increase evapotranspiration rates and the atmosphere's water-holding capacity, which can translate to less rainfall (Dai 2013).

2.2. Conflict and Violence

Droughts have also been implicated in increasing conflict, crime, and political unrest. These effects are mediated by institutions and social norms. For instance, the adversity caused by droughts is amplified in war-torn and conflict-prone areas (Buhaug & von Uexkull 2021), which may have nonfunctioning institutions and fractured norms. Conflict over water arises when institutions or social norms are stretched beyond their capacity to deal with allocation disputes. Evidence points to droughts increasing nomadic invasions in China (Bai & Kung 2011), communal violence (Bohlken & Sergenti 2010), civil war (Couttenier & Soubeyran 2014), peasant rebellion (Jia 2014, Kung & Ma 2014), coup (Kim 2016), insurgency (Hendrix & Salehyan 2012), and rebel violence (Raleigh & Kniveton 2012).

Drought can lead to social disruption and conflict through income shocks as a result of reduced agricultural income. Miguel et al. (2004) examined civil conflict in 41 African countries and found that between 1981 and 1999, rainfall shortages increased civil conflict significantly. The timing of droughts affects conflict as well. Harari & Ferrara (2018) illustrate that shocks during the agricultural growing season increase conflict in sub-Saharan Africa, while shocks outside of the growing season do not.

Drought also affects conflict through shocks in markets. Sarsons (2015) argues that agricultural income is not a primary channel through which rainfall deficits create conflict. Communal riots in

Indian districts downstream from dams still occur during drought, even though the direct effect of the rainfall shock on agricultural income is small. Instead, market channels play a role in the aggregate impact of drought on livestock prices. Evidence from Somalia indicates that a one-standard-deviation increase in rainfall shortage increases conflict by 62% mediated by livestock prices (Maystadt & Ecker 2014). Grain prices can also be impacted by rainfall shortages, which can lead to violent crimes, as was the case in nineteenth-century Germany (Mehlum et al. 2006).

Conflict emerges or is amplified when the magnitude of the drought or its impacts are larger, for instance, in disease-rich environments (Cervellati et al. 2017) and rainfed agricultural areas (von Uexkull 2014). Studies using spatially granular data refute that localized droughts impact conflict in Africa or Asia (Theisen et al. 2012, Wischnath & Buhaug 2014). However, broader drought can escalate interstate conflict, like when rainfall deficits reduce the supply of water in transboundary river basins, especially in river-sharing dyads, relative to other pairs of countries, which have upstream and downstream relations (Brochmann & Gleditsch 2012, Gleditsch et al. 2006).

A few studies find benefits of droughts. By documenting enhanced incentives of riparian states to cooperate rather than to fight, Dinar et al. (2015) suggest that water scarcity need not necessarily lead to conflict in transboundary river basins. Brückner & Ciccone (2011) argue that adverse rainfall shocks open a window of opportunity for democratic improvement due to political transition, an idea echoed by Burke & Leigh (2010).

2.3. Economic Impact

Given that water is a necessary and irreplaceable input to every economic sector, drought has the potential to impair economic well-being (Garrick & Hahn 2021, Miara et al. 2017) and degrade human and environmental health (Stanke et al. 2013, Vorosmarty et al. 2000). Agriculture is particularly vulnerable, as 80% of global agriculture is rainfed (Rosegrant et al. 2009). Below-average rainfall can reduce crop yields (Lobell et al. 2014) and water availability for livestock (Nelson et al. 2016), leading to food shortages (Cobon et al. 2016, Dasgupta & Robinson 2022, Ngcamu & Chari 2020), famine (Burgess & Donaldson 2010, Mishra et al. 2019, Njoka 2019), and social unrest (Koren et al. 2021). The risk that drought poses to agriculture will likely increase, as climate change is expected to exacerbate drought across agricultural hubs—many of which currently lack the infrastructure and resources necessary to adapt (Dai 2011, Langenbrunner 2021, Rosa et al. 2020).

Lessons about the performance of mitigation measures during drought in developed economies are context-dependent and may not hold in developing countries. Due to missing markets, institutional frictions, and lean infrastructure, droughts affect developing countries much more severely. Droughts lead to a steep decline in agricultural productivity and hence farm income. Rainfall deficit accounted for a 15–40% gap in the per-capita income of sub-Saharan Africa and the rest of developing countries between 1960 and 2000 (Barrios et al. 2010). Growth in Africa was negatively impacted by droughts during the 1980s and 1990s (Miguel et al. 2004).

Several recent review articles have highlighted the economic impact of drought. Fleming-Muñoz et al. (2023) provide a comprehensive review of studies examining the impacts of drought in Australia, finding 1,898 papers, of which 52 focus on economic impacts. Given the number and diversity of economic costs associated with drought, they suggest a three-category framework for understanding drought impacts—human health and well-being, productivity in agriculture and other sectors, and ecosystem services—and question whether current impact assessments fully incorporate costs outside the agricultural sector. Stanke et al. (2013) conduct a review focused on the health effects of drought, finding that resilience factors are critical in exacerbating or mitigating drought impacts. Ding et al. (2011) critically examine the methodologies of drought impact assessment, while Vermeulen et al. (2023) explore how the economics of drought risk reduction are evaluated.

In their review of the economics of drought literature, Freire-González et al. (2017) discuss the importance of long-term and short-term policy decisions. Water policy is fundamentally shaped by the institutions that underlie water diversions and allocations. In contrast to earlier reviews of the economics of drought, this article is focused on the role of these underlying institutions, especially water property rights, in drought outcomes.

3. AN ECONOMIC FRAMEWORK FOR DROUGHT

3.1. Scarcity and Shortage

Water scarcity and shortage have slightly different meanings in common parlance than in economics, and we begin by formalizing their economic definitions. The scarcity value of water is the difference between the marginal cost of extraction and the opportunity cost of the water. A drought always increases water scarcity as it reduces available supply. Water scarcity is typically increasing with aridity, although demand must also be considered.

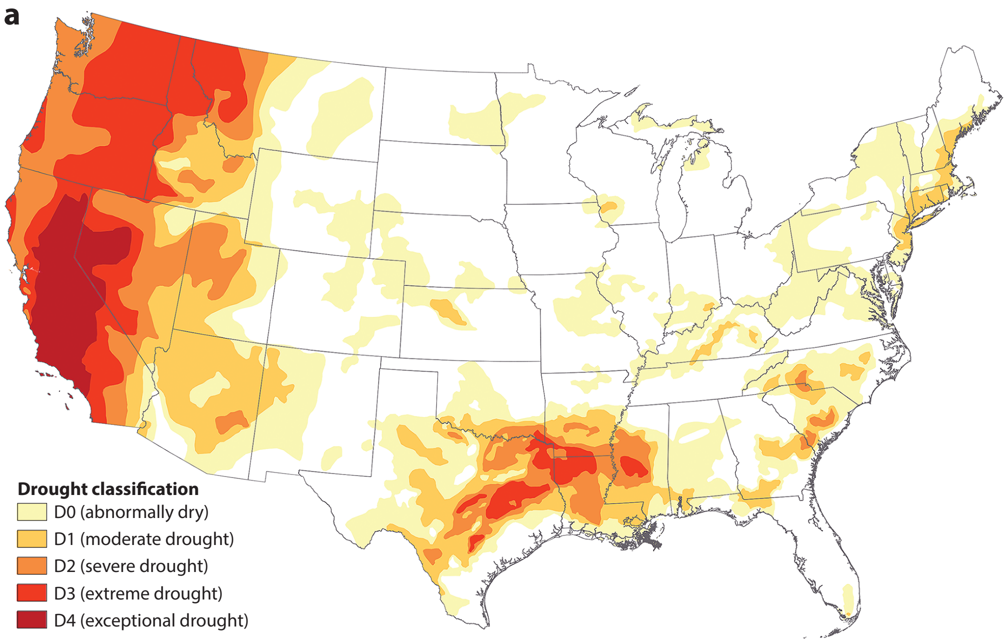
Shortage occurs when demand exceeds available supply at the current price, a deficit that means not all users will receive water. While scarcity is purely a measure of water's value relative to its availability, shortage is determined by allocation mechanisms. Hence, drought and water shortage may coincide, but shortages are ultimately a function of societal decisions about water use. Florida and the US Great Lakes region exemplify the difference between drought and scarcity. Neither area is water scarce because they both receive relatively abundant rainfall (**Figure 1*a***). Both, however, are experiencing water shortages due to the local laws and policies governing water use (Sanchez et al. 2023b) (**Figure 1*b***). Conversely, persistent scarcity across the US Southwest raises the relative value of water and incentivizes the adoption of institutions, such as water rights, that decrease the likelihood of water shortage.

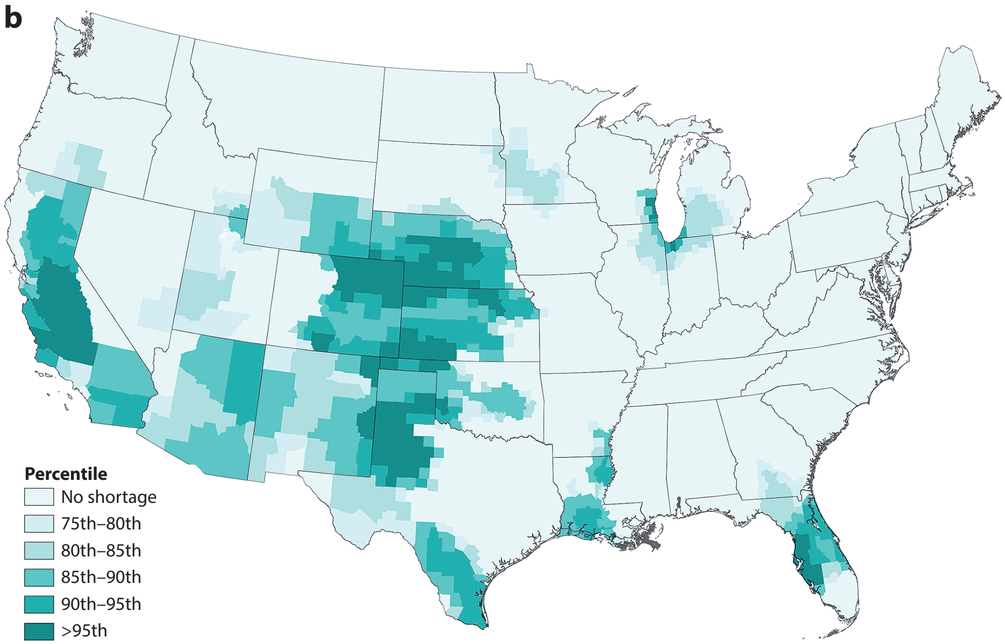
The economic impact of drought is related to its severity and the ability of the drought region to adapt. In agriculture, adaptation occurs through private mechanisms, such as changes in crops and livestock, planting and harvesting techniques and seasons, and the use of irrigation and public adaptation—e.g., breeding programs, knowledge development, and investments in infrastructure (Libecap & Dinar 2023). Irrigation is a key adaptation to allow for agricultural resilience, with the physiological relationship between crops and water informing the extent to which supplemental water is valuable.

Because water users adapt, the physical availability of water only partially explains the effect of drought, and adaptation is mediated through institutions. Water allocation institutions determine who gets water, and when, under normal conditions and shortfalls. Water distribution infrastructure determines the options available for transporting water into drought regions, moving water between users or sectors within a drought region, and the ability to access and store supplemental ground and surface water. Institutions determine the legal feasibility of alternative water allocation patterns, whereas infrastructure determines physical feasibility. The economic impact of drought is also a function of the inter- and intraregional integration of agricultural and financial markets. For instance, developed countries with integrated markets and transportation infrastructure do not see regional food shortages during drought. However, in developing countries droughts can quickly escalate into famines.

3.2. Institutions and Infrastructure

Water shortage frequently occurs under open-access conditions that lead to resource drawdown when demand is high (Ostrom 2008). The lack of regulation over the withdrawal of scarce water





(*Caption appears on following page*)

Figure 1 (*Figure appears on preceding page*)

Distribution of drought and water shortages across the United States. A comparison of drought and water shortage data shows that drought and water shortages do not always overlap. (*a*) Map constructed by the authors using US Drought Monitor data to show the locations of the various categories of drought across the coterminous United States for the week of September 29, 2015. The US Drought Monitor is jointly produced by the National Drought Mitigation Center at the University of Nebraska–Lincoln, the US Department of Agriculture, and the National Oceanic and Atmospheric Administration (**https://droughtmonitor.unl.edu/**). Each drought classification is constructed from Standardized Precipitation Index and Standardized Precipitation–Evapotranspiration Index values that are relative to normal conditions. (*b*) Map constructed by the authors using US Forest Service Resource Protection Act Assessment data from Heidari et al. (2021) to show the distribution of current (1985–2015) water shortages lasting ≥12 months and with a 50-year return period at the county level. Water shortages occur when human demand exceeds supply. Water shortage data are presented here as percentile rank, with counties in the highest percentile experiencing the worst shortages.

supplies (i.e., rivalrous, but nonexcludable) incentivizes overuse because each water user's individual marginal cost of resource extraction does not include the costs of resource depletion to others. Hence, individual water users, acting in their own interests, overconsume the resource.

Economic institutions include the laws, policies, rules, and norms governing water. They are developed or strengthened when the benefits of new arrangements exceed the costs of developing and enforcing them (Ayres et al. 2018, Sanchez et al. 2020). For example, the assignment of property rights to water provides legal certainty, incentivizes infrastructure investment (Hanemann 2014), provides a foundation for transferring water to new uses (Kendy et al. 2018, Leonard et al. 2019), and contributes to economic growth (Leonard & Libecap 2019, Sanchez et al. 2023a). Weak institutions and rights to water mean both ground and surface resources face common pool problems and overextraction, especially during drought.

In contrast, where rights are well defined and enforceable, public and private entities may have enough security to invest in large, capital-intensive infrastructure to transport water and store it for use during dry periods (Hanemann 2014, Leonard & Libecap 2019). Water conveyance infrastructure and legal clarity about water right ownership have enabled water users in arid regions to avoid shortages through agreements that import water from relatively wet regions (Heidari et al. 2021), while dams and reservoirs increase irrigator resiliency to drought by enabling water storage (Smith & Edwards 2021). In the western United States, water projects resulted in economic growth in desert environments where major rivers are far apart.

Infrastructure also has the potential to mitigate the effects of droughts in developing economies. Examining panel data of Indian districts from 1970 to 2005, Zaveri et al. (2016) find that irrigation infrastructure mitigates the consequences of droughts, showing that tube wells and subsidized electricity mitigated drought, although dams and dug wells did not. Maitra & Tagat (2019) find that dams do play an ameliorative effect in mitigating the consequences of adverse rain shocks.

3.3. Informal Adaptation

When water distribution and storage infrastructure are limited or institutions fail to solve common resource problems, populations are more directly exposed to the disruptive effects of drought. In developing economies, farming households try to mitigate income risk ex ante by changing their production or inputs. Households may grow low-risk but less-rewarding crops (Morduch 1991) or use less fertilizer so that investment losses are minimized during drought (Bliss & Stern 1982). Another form of consumption smoothing leverages social norms about marriage. In patriarchal societies, women leave their villages and co-reside with their husbands' families after marriage. Rosenzweig & Stark (1989) find that agricultural households in developing countries marry their daughters into locationally distant kinship networks to hedge income risk associated with local drought. Ethnic networks also provide insurance for consumption smoothing in Africa in times of adverse rainfall shocks (Grimard 1997).

If credit markets were functioning well, then transitory shocks, such as a year of drought, would not affect consumption. Despite a decline in transitory income, borrowing and saving would smooth consumption. However, evidence points to some degree of consumption smoothing. Farmers can use their precautionary savings and assets to offset the income shock to some degree (Paxson 1992, Rosenzweig & Binswanger 1993), but poor agricultural laborers and very small or micro farmers face constraints (Morduch 1999, Rosenzweig & Binswanger 1993). Farming households resort to other informal ways to cope ex post. There is reciprocal gift giving, but it does not smooth consumption perfectly (Rosenzweig 1988). Households sell productive assets such as bullocks during shocks and buy them as buffer stock in good years (Rosenzweig & Wolpin 1993), although this does not ensure recovery to pre-shock wealth levels (Fafchamps et al. 1998). Remittances are another strategy to reduce consumption loss risk (Yang & Choi 2007).

A variety of labor supply decisions are also used to smooth consumption. Household males increase their market hours of work when farm income falls (Kochar 1999, Rose 2001). Household members are also willing to supply labor at a lower wage (Jayachandran 2006). Households migrate within the country and internationally (Gray & Mueller 2012, Munshi 2003). Children's school attendance is reduced as a form of self-insurance, possibly to conduct household chores or work (Jacoby & Skoufias 1997).

Despite evidence that households try to insure themselves through informal adaptations and that formal insurance products are beneficial, the demand for formal insurance is low (Ahmed et al. 2020, Cole et al. 2013). Karlan et al. (2014) show that weather insurance removes downside risk and leads to higher investment relative to cash grants by farmers in Ghana. Informal network-based insurance, however, likely crowds out formal insurance (Mobarak & Rosenzweig 2013). Another arbitrary feature of most index insurance products is that they are sold to landholders but not the more vulnerable and poor landless laborers. Offering such products to the poor and landless can be welfare-enhancing (Mobarak & Rosenzweig 2014). The lack of uptake for formal insurance products in some settings offers a useful illustration of the importance of local context in predicting the effectiveness of introducing new institutions for managing drought risk.

4. WATER PROPERTY RIGHTS

4.1. Determinants of Drought Allocations

The design and evolution of water right institutions are a function of the unique environmental settings and community priorities related to the benefits of governing water (Ostrom & Ostrom 1972). These institutions, in turn, determine who gets water during shortage. In the eastern United States, relatively abundant water access is reflected in the riparian doctrine, which generally provides unfettered use rights to lands bordering waterways. In the arid US West, where drought is more frequent and severe, appropriative rights emerged that separated water from land and facilitated investment in irrigation (Leonard & Libecap 2019).

In the Middle East, where rainfall averages a scant 125 mm/year, communities rely almost exclusively on groundwater. *Aflāj* (singular *falaj*) water systems, which pump groundwater from a centralized source and deliver it to a community via gravity-fed canals, emerged over a millennium ago and continue to govern water use (Bandyopadhyay & Mershen 2022). *Aflāj* water rights are defined as time-based shares rather than absolute quantities, so shortages are shared proportionally as flow rates diminish.

Acequias, which refer to water rights and water delivery systems, govern surface water in parts of the US Southwest, Mexico, the Andes, and Spain. *Acequia* water rights are allocated to individuals on a shared ditch system as volumetric shares. Allocations as well as curtailments during times of drought are proportional to an individual's irrigated acreage. *Acequia* ditch systems are collectively owned and managed by their members, all of whom receive an equal vote regardless of their water right shares.

Appropriative, *aflāj*, and *acequia* water rights embody multiple qualities specified by Ostrom (1990) that have enabled communities to effectively manage water scarcity. Each system bounds resource use based on rules that emerged in response to local circumstances, is recognized by higher levels of government, has monitoring and enforcement mechanisms, and is legally enforceable.

Each allocation system specifies how shortfalls are distributed during drought. Appropriative rights are curtailed based on their relative seniority, with the oldest (senior) rights being filled in their entirety before junior right holders receive water. Appropriative rights provide an institutional foundation for reallocating scarce water to where it is needed most via markets. Seniority-based curtailments, however, introduce heterogeneity in risk across otherwise similar water users and can lead to inefficiencies: Senior appropriators receiving their full allocations during shortage experience diminishing returns to each marginal unit of water, while junior appropriators, who may not receive any water, could generate a higher marginal benefit from that same unit of water (Bennett et al. 2000). Senior water rights have enabled irrigators to maintain crop production during drought (Nelson & Burchfield 2017). Junior appropriators adapt to relatively short-term droughts by switching to less profitable but more drought-resilient crop mixes and fallow more acreage than senior appropriators during relatively severe, long-term droughts (Cobourn et al. 2022).

Conversely, proportional curtailments across *aflāj* and *acequia* rights can yield more equitable, efficient outcomes, provided that users are similar. Irrigators in a shared system may mitigate risk by selecting drought-resilient crops. Because the shortage is shared, they collectively maintain higher yields, and no single irrigator bears the cost of fully curtailed water rights (Ji & Cobourn 2018). Unlike in priority-based systems that discriminate against new entrants, proportional shortage sharing may lead to overcapitalization because later entrants lack the incentive to curb investments (Smith 2021). Proportional sharing systems may be inefficient when users with differing marginal products of water are forced to share cutbacks equally.

4.2. Market-Based Reallocation

Across all systems, the ability to transfer water during shortage can address allocations that do not, a priori, equalize the marginal product of water across users during drought. Reductions in physical water supplies during drought increase scarcity by raising both the marginal cost of extraction and the opportunity cost of water. As prices rise, formal markets for water rights can help manage scarcity and avoid shortages by reallocating water to higher-value uses within and between economic sectors (Browne & Ji 2023, Garrick et al. 2019a).

Economic analysis consistently suggests that water markets create large gains from trade and that these benefits occur primarily during times of shortage (Hagerty 2022, Rafey 2023). Institutional restrictions on water markets may reduce drought resiliency and be costly to water rights holders, who would otherwise benefit from sales (Grafton et al. 2012). For example, as drought exacerbates water scarcity in the Lower Colorado River Basin, Arizona water users are employing market mechanisms to avoid federally mandated cuts to the state's water deliveries from Lake Mead, the region's largest reservoir. The 2023 Colorado River Indian Tribes (CRIT) Water Resiliency Act authorized CRIT to market its water rights to water users in Arizona. CRIT has high-priority rights to roughly 6% of the Colorado River's annual flow and uses 98% of its entitlements in flood-irrigated agriculture. CRIT and the State of Arizona are working toward an agreement where Arizona would lease water from CRIT to store in Lake Mead, thereby maintaining reservoir levels and avoiding curtailments to state water users.

Short-term leases are a relatively nimble response to drought, as they are more flexible and typically have lower transaction costs than permanent sales. Several states across the US West expedite the administrative process for approving short-term leases (Szeptycki et al. 2015). During drought years, environmental groups in the Pacific Northwest increasingly enter into short-term leases with irrigators with the goal of augmenting streamflow (Kendy et al. 2018). Split-season and partial leases allow irrigators to reduce water use at the margin while continuing to farm (Khanal et al. 2021). Lessors can maximize the impact of their funding on streamflow augmentation by strategically leasing water for specific stream reaches during critically dry periods.

4.3. Informal Markets

Informal water markets are widespread, particularly in areas where water rights are insecure and water infrastructure is insufficient (Kariuki & Schwartz 2005). Although there are few analyses estimating their role in drought adaptation, a growing literature highlights their importance in allaying the consequences of water shortages (Garrick et al. 2019b). Urban water vendors, ranging from sachet water vendors in West Africa to water tankers in Jordan (Klassert et al. 2023) and India (Venkatachalam 2015) fill gaps between supply and demand due to inadequate piped infrastructure or water treatment.

Prices of water delivered from fixed-point water sources via water vendors can exceed piped water pricing by up to 100% (Garrick et al. 2019b). Despite the relatively high marginal price of water, there is evidence that informal markets are more competitive than piped networks (due to low barriers to entry) and are therefore more reflective of the true cost of water (Wutich et al. 2016). However, because informal water markets typically rely on unregulated groundwater, their ability to reconcile supply and demand during drought will diminish as groundwater is depleted (Klassert et al. 2023). Evidence from Scanlon et al. (2022) showing that groundwater quality, relative to other sources, declines most as drought days increase further underscores the vulnerability of already marginalized groups who depend on unregulated water sources.

5. INSTITUTIONAL EVOLUTION

5.1. Drought as Impetus for Adaptation

Drought often serves as the impetus for changes in water property rights, infrastructure, and markets. In the United States, drought between 1890 and 1896 led to a dramatic reversal of westward immigration trends and economic depression across the Great Plains. The drought was the primary impetus for the beginning of federal involvement in irrigation, leading directly to the Reclamation Act of 1902. The Dust Bowl, a period of drought and wind erosion that occurred in portions of the Great Plains from 1930 to 1936, transformed the social and economic lives of residents of western states and altered migration patterns. Subsequent adaptation on a variety of margins, including water rights, large infrastructure projects, and the widespread adoption of groundwater irrigation, along with new crop genetics and insurance programs, limited drought severity (Edwards & Smith 2018). Severe droughts in the 1950s and 1970s did not result in the same levels of wind erosion or similar levels of economic or social upheaval (Hansen & Libecap 2004).

Similarly, in Australia "[t]he severity and longevity of the Millennium Drought in the 2000s exposed the need to respond to water overallocation and environmental problems" (Grafton & Wheeler 2018, p. 493). In response, Australia implemented a series of reforms intended to address the current drought and future shocks. Adaptation measures adopted included the construction of new infrastructure, the facilitation of water markets and the buyback of water entitlements, and sustainable diversion limits to protect ecosystems (Grafton & Wheeler 2018). Today, Australia has the most mature water markets in the world. These markets responded to subsequent severe droughts (2006–2009 and 2017–2019) with dramatic increases in both temporary and permanent water entitlement prices (Wheeler 2022). Institutions that allocate water during drought based on price respond to increased scarcity without creating shortages, which is generally viewed by economists as an efficient response. We discuss the equity implications in the next section.

5.2. Adapting Water Rights

Water scarcity and drought have also spurred changes in water rights. The prior appropriation doctrine emerged in the western United States in the mid 1800s in response to drought (Anderson & Hill 1975). In the eastern United States, sufficient water existed for economic development to occur with proportional sharing of cutbacks during drought under the riparian doctrine. In the western United States, water users needed legal certainty about how much water they would receive during drought and their right to use water on land not adjacent to waterways. The prioritization and quantification of water rights under the prior appropriation doctrine provided a legal framework for secure investment in a setting where overall water availability was not well known (Leonard & Libecap 2019).

In Chile, the 1981 water code implemented a formal water property system with rights freely tradable and separable from land transactions, applying to both surface and groundwater rights. Ayres & Molina (2023) find that these rights allow markets to address persistent drought with increased market transactions of both ground and surface water rights. Additional equity concerns, however, have emerged because Indigenous and environmental users did not receive water right allocations, an issue we turn to in the following section.

5.3. Irrigation

Adaptation via investment in infrastructure, technology, and markets is undertaken in response to drought. Investments in the western United States in irrigation, water storage and transport, groundwater wells and pumps, and new crop genetics smoothed agricultural income shocks. Smith & Edwards (2021) find that prior to 1950, dry and significantly dry years reduced crop value per acre relative to normal years—losses of roughly 24% in years of significant drought. Over time, commodity markets, new insurance markets, government-sponsored crop insurance, and enhanced inputs and techniques enabled an overall reduction in the impact of drought after 1950 to 13% crop revenue losses. Even greater smoothing occurred in areas with access to groundwater via aquifers or surface storage due to large dams, with these areas seeing no income losses in moderate or extreme drought years. Water property right institutions are key to understanding the ability of other regions to similarly mitigate drought via investment in irrigation (Smith & Edwards 2021).

6. INEQUITY IN WATER DISTRIBUTION DURING DROUGHT

6.1. Initial Allocation

Who benefits from existing water right institutions is often determined by the original water right allocations. Contemporary water right ownership tends to be stratified along the dimensions of race, gender, and socioeconomic status, leaving historically marginalized groups in many countries disproportionately vulnerable to drought (Harrington et al. 2023). Current disparities in water right ownership are a function of who, historically, could lay claim to water and the high transaction costs associated with transferring water rights to new users (Sanchez et al. 2020).

In the United States, for example, riparian water rights in the east are appurtenant to the land and therefore held by landowners. Appropriative rights in western states are established and maintained through beneficial use, which historically required diverting water. Owning land on which water could be continuously and beneficially used was therefore an implicit requirement for establishing a water right. However, land ownership opportunities for nonwhite people in the eighteenth and nineteenth centuries, when water property rights were established, were extremely limited. Black populations were not considered citizens until the passage of the Fourteenth Amendment in 1868, and Native Americans were ineligible for citizenship until 1924. Women were also not allowed to independently own property until well after initial water rights were established.

Water rights remain concentrated in irrigated agriculture, and patterns of ownership have persisted. A 2023 analysis estimated that nearly 90% of California's water is either owned or controlled by white populations (Fidell & Shipman 2023), underscoring the long-running inequities associated with initial water allocations and seniority-based curtailment rules.

Relative to irrigated agriculture, municipal water suppliers across the West hold junior water rights but have relatively inelastic demand and long planning horizons. Cities have adapted to drought by acquiring water from irrigators, financing infrastructure improvements, and managing demand by increasing water prices (Dilling et al. 2019). However, Klasic et al. (2022) find that relatively small, low-income communities often cannot afford to improve water systems or purchase water and lack connectivity to larger water infrastructure that would enable them to import water.

Insufficient surface water has prompted many communities, in the United States and elsewhere in the world, to rely on unregulated groundwater (Jasechko & Perrone 2021). Levy et al. (2021) find that drought-induced groundwater pumping by irrigators in California's Central Valley has led to episodic groundwater contamination. Excessive pumping draws shallow, contaminated groundwater to depths that are typically accessed by public drinking water wells. Contamination disproportionately impacts low-income and minority communities, which lack alternative drinking water sources (Aiken et al. 2023).

6.2. Indigenous Water Rights

Indigenous communities face unique vulnerability to drought because they were historically excluded from water right allocations, a problem that has not been rectified in many cases. In the United States, Australia, New Zealand, Canada, South and Central America, and South Africa, water rights were established for agriculture during colonization in the eighteenth and nineteenth centuries without regard for the existing needs or water use of Indigenous populations (Sanchez et al. 2023a). Since then, surface water in most basins has been fully allocated. Without legally enforceable water rights, many Indigenous communities' water access is contingent on all other rights being fully satisfied first.

In the United States, the Klamath Tribe was unable to maintain streamflow to sustain its fishery in Oregon during a 2001 drought because it lacked legally enforceable water rights. Instead, the Klamath River water was entirely diverted for upstream agriculture, and the tribe's fishery was decimated (Boehlert & Jaeger 2010). In Chile, concern over the quantity of water rights being transferred to mining companies in perpetuity grew due to a lack of water availability for Indigenous communities from traditional water sources (Edwards et al. 2018). The town of Quillagua, downstream from mining diversions, was forced to truck in water during dry periods to provide drinking water to its residents.

While some Indigenous communities have acquired legally enforceable water rights in the last several decades, doing so after basins have been fully allocated and in the context of increasing scarcity has put them at a disadvantage. Nearly 20% of federally recognized reservations in the United States have acquired legally enforceable water rights through settlements negotiated with neighboring water users. However, entitlement volumes are decreasing over time and with scarcity (Sanchez et al. 2020). A lack of water infrastructure to support on-reservation water use and barriers to off-reservation water marketing have meant that tribes use a fraction of their total entitlements, mostly for relatively low-value agriculture, and forgo up to $1.8 billion annually in lost leasing revenue (Sanchez et al. 2023a). Hence, they cannot fully benefit from their water rights or adapt to drought conditions to the same extent that off-reservation water users can.

In Australia, *Mabo v. Queensland* (1992) recognized Native title rights to water. But because the court has interpreted Native title rights for cultural and traditional instream uses rather than as consumptive rights, Aboriginal communities have been unable to use them for economic development (Macpherson 2020). The narrow interpretation of Native title rights preserves water for consumptive use by non-Indigenous right holders (Jackson et al. 2021). Although Native titles may protect instream flow during drought, restrictions on their use for economic development do little to bolster resilience to other effects of drought, like rising food prices or other economic disruptions (Lansbury Hall & Crosby 2022).

6.3. Infrastructure

Water infrastructure mediates the effects of drought by enabling continued access to water and ensuring water quality standards during times of shortage (Lund & Medellín-Azuara 2018, Smith & Edwards 2021). The extent to which various communities benefit from water infrastructure is largely a function of institutional governance (Lund & Medellín-Azuara 2018). Representation in environmental policy ultimately shapes resource allocations and funding decisions, which factor into a community's ability to adapt to drought. Therefore, the distribution of such amenities can be inequitable, with marginalized populations (i.e., those with less political influence) being less likely to see investments in water infrastructure (Pandey et al. 2022).

Deitz & Meehan (2019) show that Native American, Black, and Hispanic households in the United States are more likely than their white counterparts to have incomplete plumbing, which Mueller & Gasteyer (2021) link to a disproportionate number of drinking water quality violations in rural, minority, and socioeconomically vulnerable communities. Infrastructure inequalities that align with socioeconomic status in urban areas in southern Africa have meant that severe droughts exacerbate existing inequalities (Rusca et al. 2023). Already vulnerable households are less able to absorb the costs of water insecurity wrought by drought and are more likely to experience food insecurity and adverse physical and mental health (Brewis et al. 2020, Rhue et al. 2023). That these same households also tend to have less access to other physical infrastructure such as health care facilities further compounds the costs of water insecurity (Timyan et al. 2018). As discussed previously, informal market allocations of water, like water trucks, tend to be expensive and may not be available to the most vulnerable populations.

6.4. Informal Institutions and Equity

In developing countries where formal water rights and allocation institutions do not exist, drought also creates inequitable burdens, which fall disproportionately on women and children (especially girls). In Zimbabwe, children are persistently stunted if born during droughts (Hoddinott & Kinsey 2001). Rose (1999) finds that the survival probability of girls is reduced during rainfall shortages in India. In Tanzania, inadequate rainfall leads to the killing of elderly women perceived as witches (Miguel 2005), and dowry killings increase in India in times of droughts (Sekhri & Storeygard 2014). Women drop out of educational institutions and spend more time doing household chores in India (Maitra & Tagat 2019). In Uganda, households experiencing droughts withdraw older girls from schools but not boys or younger girls (Björkman-Nyqvis 2013). When schooling is free, girls enroll in schools during drought, but their test scores are worse than boys, indicating that households reduce the allocation of resources to girls. Cameron & Worswick (2001) find similar patterns in Indonesia, while Jensen (2000) demonstrates that critical investments in all children are undermined due to droughts. Children face increased malnutrition, decreased medical consultation on falling sick, and a drop in school enrollment. There is also evidence that early childhood exposure to abundant rainfall has implications for later life outcomes of women in Indonesia mediated through increased schooling (Maccini & Yang 2009). Cole et al. (2023) show differential abilities of wealthy and poor to adapt to drought-induced drinking water stress.

7. CONCLUSION

In this review, we have focused on water institutions, and particularly water rights, as a key explanatory factor in the outcomes of drought. Stronger property rights to water and more robust institutions appear to increase drought resiliency, and conversely, when existing institutions are inadequate, drought impacts can be widespread and lead to civil conflict. The importance of these institutions in economic decision making leads to a key paradox: Secure water property rights provide social benefits during drought but may also be inequitable by a variety of measures. In developed economies with strong water right institutions, vulnerable and marginalized groups hold less secure or nonexistent rights to water. Fundamental questions remain about how these inequities can be resolved while maintaining the key functions that property rights provide and in the face of political opposition to redistribution.

While a thorough review of drought and ecosystem function was beyond the scope of this article, there are similar questions about how water rights and the infrastructure that facilitates drought resilience affect natural capital stocks. In their review articles, Ding et al. (2011) and Freire-González et al. (2017) emphasize that nonmarket losses due to drought, for instance, the reduction of natural capital of water stored in ecosystems, are poorly integrated into estimates of economic impact. Put another way, is the resilience to drought in developed countries sustainable, or is agricultural water use racking up a natural capital deficit that will come due in the future? Here too, new research is needed to understand how to design and implement water property right institutions that protect ecosystem function and provide drought resiliency while remaining politically feasible. Research on example institutions like those under the Murray-Darling Basin Plan in Australia and the Sustainable Groundwater Management Act in California could provide important lessons provided sufficient attention is paid to institutional details and local context.

The importance of caution in efforts to apply lessons from one institutional setting to another cannot be overstated. Although developing economies fundamentally lack strong water property rights institutions, these stem from a variety of proximate causes. Undoubtedly, lessons from institutional arrangements in Australia or the western United States, for instance, could provide guidance to improve water management. How such lessons could be applied is an area in need of more research. Without the proper local institutional and social context, the transfer of water institutions may at best be ineffective and potentially much more problematic. Although generally beyond the scope of this review, research into the role of local collective governance of water resources and the risk that new governance systems could disrupt existing, effective governance, should not be overlooked (e.g., Ostrom 1990).

Large declines in precipitation led to the decline of ancient civilizations like the Akkadian, Maya, and Anasazi. In contemporary times, many commentators have suggested the next great wars will be fought over water, as climate change increases the frequency and duration of drought, and population growth stresses existing supplies in arid areas. This review suggests that the disputes and conflicts over water may not manifest as a war over the resource directly, but instead it may be conflicts over the institutions and norms—the fabric of society—that allocate water and its associated benefits. Digging into the workings of these institutions is crucial to understanding the economics of drought.

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