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WATER MARKETS AND TRADING

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■ **Abstract** Since the 1970s, supply augmentation strategies to meet water needs have waned, and governments have increasingly focused on demand management measures, including voluntary water transfers. Water demands have also changed as expanding urban growth, changes in agriculture, and increasing concern for the environment compete for water. Water rights regimes based on queuing principles lead to an inefficient allocation of water resources and may also result in other inefficiencies, such as overuse of land and inadequate adoption of capital-intensive conservation technologies. Water trading based on transferable water rights has been advanced as a solution to these problems. Trading helps equalize the marginal prices faced by various water users, thereby providing information about the value of water in alternative uses and creating compatible incentives. Putting water markets into practice introduces real-world complications of transaction costs and third-party externalities. We present these complications along with some major criticisms of water markets, and actual cases of water trading are discussed. We conclude with avenues of potential future research.

CONTENTS

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SUPPLY AND DEMAND

The water-trading literature is voluminous, with a 1997 survey article (1) listing over 200 works spanning the economic, legal, policy, and scientific dimensions of water markets. This review, mostly of the academic and economic literature on water markets, highlights major works and adds important recent contributions. We make special reference to water marketing in the western United States, especially in California.

A Brief History

From the late nineteenth century to the 1970s, water supply management in the western United States (and in most semiarid agricultural areas across the world) has been through heavily subsidized supply augmentation. The government increased supply by building dams, reservoirs, and canals to capture surface runoffs and deliver it to agricultural and urban users while also generating hydroelectric power and providing flood control. Despite the prodigious resources needed to move water through or over mountain ranges and across hundreds or thousands of miles, water prices were kept low. Furthermore, demand for water has increased because of expanding agriculture and growing populations. In the western United States, about 80% of water used is used by agriculture, with the rest going to municipal and industrial uses. Water sales often violate the economic law of one price, with urban users regularly paying more than agricultural users, up to ten times more, for water even after factoring in transaction, delivery, and treatment costs (2, 3).

The period since the 1970s has seen the policy of subsidized supply augmentation replaced by an emphasis on better management and reallocation of existing supplies. Hence, our analysis makes the simplifying assumption that existing supplies are a binding constraint. The resulting water scarcity is what makes water an "economic good." Readers interested in historical analyses or engineering perspectives of water are directed to several good books (4–6).

Decomposing Water Use

Water analysts typically classify human use of water into agricultural and urban use; however, current analyses make further differentiation. Agricultural use is divided by agricultural output or crop. Urban use is divided into municipal and industrial (MI) use, which is further split into residential and commercial use. Some uses do not fit this classification easily. Instream flows are an environmental use that is needed to sustain ecosystems and protect wildlife. Hydroelectric power generation is sometimes classified as an industrial use and sometimes is its own category. Recreation and transport uses are often left out of analyses. Researchers, agencies, and governments vary in their usage of the above classifications.

Consumptive use vs nonconsumptive use is another important distinction. The standard example of consumptive use is a farm irrigated by a nearby river. Crops consume a fraction of the applied water via evapotranspiration; the remainder might be a return flow to the river available for downstream users. One California definition of "consumptive use" is applied water that cannot be put to further use by downstream users, which includes water that drains to a saltwater body. The standard example of nonconsumptive use is hydroelectric power, where all the water used passes through to downstream users. Water applied to a farm that percolates underground water (which can later be pumped out) is sometimes seen as consumptive or nonconsumptive, a distinction important for trading (7).

Despite these complications, the term "water used" is sometimes applied without clear definitions and too often must be understood (or guessed at) contextually. Generally, and unless otherwise indicated in this review, water used refers to all water applied to agriculture, without adjustment for return flows, plus all MI use.

Optimal Allocation

The socially optimal water allocation is one whereby the net output of a region is maximized and is often conceptualized as the choice of a benevolent social planner. In economics, the social optimum is termed Pareto efficient, an allocation of resources (including compensating transfers of money) such that no person can be made better off without making someone else worse off. A third way of conceptualizing the social optimum is a situation in which all welfare increasing trades and technology choices are implemented. The central economic result is that the marginal values of water across all uses are equated. Economists call the social optimum "efficient" because water is allocated to those who value it the most.

Despite criticisms by other disciplines against this economic approach, we posit that the social optimum is the correct policy target, but the formation of the social optimum involves subjective value judgments. Criticism among economists and across disciplines generally is aimed at how water-use values are determined and what uses are included. Economists have developed methods for determining the economic value of water in various uses (8). Other researchers have questioned the appropriateness of using a willingness-to-pay measure as the foundation of value (9). Despite varying viewpoints, the consensus Dublin Principles, arising from the 1992 International Conference on Water and Environment, recognized both water's scarcity and a need to effectively allocate it (10) as well as its essential role in sustaining "life, development, and the environment."

Regardless of discipline, any conception of the socially optimal allocation of existing supplies seems to include three key changes from the current allocation. First, early advocates of water reallocations identified water transfers from low-valued agriculture to high-valued municipal and industrial uses as the principal driver. Second, and more recently hypothesized, water transfers within agriculture from low-value to high-value uses. Indeed, agriculture-to-agriculture transactions comprised 20% of the trading volume of the 1991 California Drought Water Bank (CDWB) (11) and 26% of water share trading in the Colorado-Big Thompson Project area (12). Third, with trading driving up the price of water, investment in water conservation technology should increase (13–15).

A Nonstandard Commodity

If water were a standard commodity, free-market allocation of resources would be efficient and no regulation would be necessary. Water, however, is not a standard commodity.

Because water is so ubiquitous, most analyses assume that water's definition and characteristics are commonly understood, and this assumption can lead to confusion. As scientists like to remind us, water is neither created nor destroyed but cycles through Earth's hydrological cycle. Water policy addresses the scarcity of usable freshwater, which obviously excludes saltwater but also excludes water that is contaminated by naturally occurring and man-made materials and chemicals. Usable freshwater is primarily available as precipitation, as surface water, or as usable groundwater, although desalination is well established in many parts of the world and being considered in San Diego and other parts of California (16).

Quantity is only one relevant dimension of water as a commodity. In this review and in most papers, "water" refers to usable freshwater, measured in units such as acre-feet (AF) or million liters (ML). Such a representation ignores that precipitation and surface water are usually flows and not stocks, generally referring to a given quantity per year; 100 AF generally refers to 100 AF per year. Second, not all water use is consumptive, and there is considerable value of non-consumptive uses (e.g., hydropower generation and environmental benefit) as well as further downstream use of return flows. Third, precipitation and surface flows vary dramatically year to year because of weather conditions, and the reliability of water availability usually conditions its value. Fourth, water quality matters, with usability dependent on water's specific application. Lastly, timing, location, and elevation are critical because water is bulky and incompressible and cannot be cheaply stored nor quickly transported large distances or elevations. These factors, among others, make water different from the typical abstract characterization of a commodity solely by its quantity. Oversimplification can lead to serious errors in analysis.

Drought Response

Adding the complexity of weather variability, the socially optimal allocation of water becomes a contingent allocation incorporating reallocation in drought years. Unlike predictable long-term demand changes driven mainly by urban or agricultural expansion, the suddenness of a severe drought supply shock eliminates most technological adjustment options. In practice, water deliveries drop substantially, with a larger drop to agricultural deliveries.

The social optimum would include two important features. First, within agriculture, some farms would reduce acreage rather than apply grossly inadequate water, some farms would fallow fields, and some farms (for which inadequate water would cause multiyear damage to crops such as trees and vines) would receive nearly full water supplies. Second, aggregate agricultural use would decrease more than aggregate urban use because urban use is relatively price inelastic. During the 1991 CDWB, after decreased deliveries were implemented, trading consistent with the above two predictions occurred (11).

Early Literature

Some of the early and often-cited advocates for voluntary water markets as a means of reaching economic efficiency of water use were Milliman (17), Hartman & Seastone (18), Vaux & Howitt (19), Howe & Easter (20), Frederick & Gibbons (21), and Saliba & Bush (22). These authors carefully considered the concept of third-party effects and transaction costs as factors complicating and limiting the usefulness of water markets. Since their early advocacy, water trading has been applied limitedly with concomitant research into transaction costs and third-party effects that hinder the development of water markets. There has also been an increased emphasis on the role of institutions, the distribution of benefits, and the value of instream flows.

WATER RIGHTS AND PRIOR APPROPRIATION

Prior appropriation, the dominant water rights doctrine in the United States (23), is a queuing system often summarized by the phrase "first in time, first in right." Before a river is fully appropriated, anyone can establish a water right by simply appropriating, or using, water. If a river's flow is overappropriated, senior rights holders (those with earlier rights) get their full allocation prior to any allocation to junior appropriators. Typically, agricultural users hold more senior water rights (24). The warabandi water allocation system used in many parts of India and Pakistan is a queuing system whereby priority is based on physical location rather than seniority (23). This section introduces appropriative water-use rights and the economic distortions they can produce. Several more detailed accounts of water rights are available (25–27).

Major Provisions of Prior Appropriation

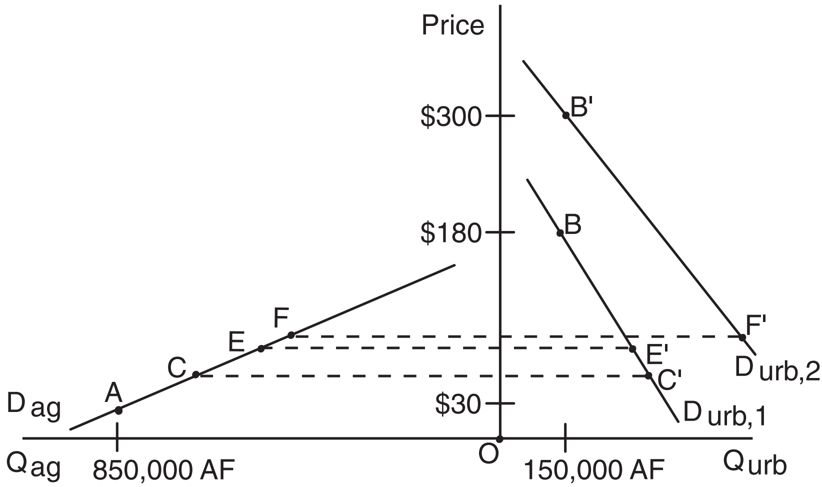
There are two major provisions that appear in prior U.S. appropriation settings: "beneficial use" and "cancellation for nonuse." Beneficial use states that a right is only recognized if the water is put to a beneficial use such as agricultural or urban use. This provision exists to prevent wasteful water use and prohibit speculation by claiming rights without actual use. Cancellation for nonuse, also called forfeiture, means that the right can be lost if the water is not used for a certain period of time, typically five to ten years in the western United States.

Property rights to water are not equivalent to private ownership. In most countries, water is owned by the state, which grants use rights to private parties and can put conditions on its use. In California, beneficial use requirements have changed over time, reflecting increasing concern for the environment and changing regional demands for water (25). For example, it is conceivable to mandate water efficiency in agriculture, similar to existing urban water restrictions. In contrast, the prior appropriation system in Chile does not apply beneficial use requirements nor does it cancel rights for nonuse. Furthermore, Chile's constitution grants the government very little ability to regulate use (10).

Inefficiency of Prior Appropriation without Trade

Prior appropriation without trade provides poor incentives for conservation and crop choice. Consider a stylized example under ideal textbook conditions of no externalities or transaction costs. Suppose that a river has an average flow of 1 million AF; 850,000 AF of senior water rights are held by the agricultural (AG) district, and 150,000 AF are held by the urban (URB) district, which may have outside sources. With prior appropriation, allocation and pricing are not determined in a market context. Figure 1 plots the demand curves for both sectors, labeled as D_{ag} and $D_{urb,1}$. Without trade, the demand curves do not represent prices of given quantities.

What are the prices and quantities in an average flow year without trade? In an average year, points A and B represent the marginal value of water, \$30 and \$180, in each sector at the prior appropriation quantities. However, actual prices may be lower; prices are often set using the concept of cost recovery for an agricultural or urban district. If the price set in AG is less than \$30, the quantity demanded



*Erratum **Figure 1** Hypothetical demand (D) curves and allocations for agriculture (ag) and urban (urb) water uses under growth and drought, trading and non-trading, and normal vs increased demand scenarios. D_{urb1} and D_{urb2} represent hypothetical demands before and after growth, respectively. Average allocation is 1 million AF with agriculture receiving 850,000 with top priority. In a normal flow year, A and B are final allocations of water without trading, whereas C and C′ represent final allocations and market clearing prices with trading. With increased demand, A and B′ are final allocations of water without trading, whereas F and F′ represent final allocations and market clearing prices with trading. In a drought year with 850,000 AF of flow, A and O are the final allocations, whereas E and E′ represent final allocations and market clearing prices with trading. Abbreviation: AF, acre-feet.

at that price would be higher than 850,000 AF, and there would be an apparent shortage. Furthermore, the last acre-foot used by AG is worth only $30, but the last acre-foot used by URB is worth $180. Although these prices are hypothetical, they are on the order of the price spreads for agricultural-to-urban transfers in southern California (28). A voluntary trade between the two sectors would increase welfare and lead to more economically efficient use.

A second inefficiency stems from distribution in the event of a drought. In a hypothetical drought year, the river supply is 850,000 AF. URB would receive no water from the river, even though it values water more, whereas AG would receive its full allocation. In reality, such a distribution would probably not occur, but the prior allocation property rights structure, absent trading, dictates such a result.

A third inefficiency comes from the response to urban growth. Suppose that urban growth expands the demand of URB to $D_{urb,2}$. The marginal value of water increases to $300 at point B′, further increasing the potential gains from trade, but the URB allocation remains fixed at 150,000 AF.

*Erratum (27 Nov. 2006): See online log at http://arjournals.annualreviews.org/errata/environ

A final inefficiency has to do with conservation technology choice. Caswell & Zilberman (13) have investigated modern irrigation adoption and linked it to the price of water. Hence, absent trade, the low price of water may cause AG to underadopt water-saving irrigation technology.

If trading is added (with the strong simplifying assumptions of no third-party effects or transaction costs), the four inefficiencies above can be overcome. In an average year, allocations and marginal market prices would be given by C and C′. During a drought, both appropriators would share in the decrease in allocation, with the equilibrium at E and E′. Urban growth would be accommodated with an increase in URB use to F′ and a decrease in AG use to F. In each case, voluntary trading achieves the social optimum, regardless of initial allocation and prices. Hence, even if AG customers were charged a low price for water, their opportunity cost would be the market price. This price would generate the correct incentives for water conservation technology choices.

Transfers and Transferability

The National Research Council (29) defines a water transfer as "any change in the point of or a change in the type or location of use." Within this definition, transfers have a wide range of complexity. The simplest transfer is within an irrigation district. More complicated transfers are across districts but within a given river basin. The most complicated transfers are interbasin transfers. There are several types of water transfers including permanent water sales and temporary water leases, discussed in a later section. Here, we focus on some basic property rights issues.

To the best of our knowledge, water transfers in the United States and abroad are all subject to some form of state approval and "no injury" rules that protect third parties, although the strength of these rules vary widely. The protection is usually in the form of the right to protest the transfer. Across states, the no injury rules vary with respect to who has legal standing and the criteria used to determine the claim. At a minimum, other water rights holders have standing to protest the transfer, but many states allow private individuals or municipalities to initiate protests. Recent trends indicate a broadening of the law to consider claims based on public interest considerations, instream flow environmental protections, and area-of-origin impacts. In some states, irrigation districts have the right to veto out-of-basin transactions, and environmental groups are sometimes allowed to petition for minimum streamflows (26).

There are exceptions to the transfer provisions discussed above. Federal water project deliveries are subject to special rules that may make it difficult to transfer water out of basin, but easier to transfer within basins (30). In Chile, the general courts, rather than specialized water courts, hear injury claims and have been very reluctant to mitigate potential effects of transfers, even if the government is the protesting party (10).

Other Regulations

Registration is another important regulatory concept. States today often require that water rights must be registered to be valid. In the late nineteenth and early twentieth centuries, rights did not need to be registered, presumably because of administrative difficulty coupled with abundant water. It was more efficient for parties to seek a judicial decision when a conflict occurred. As water conflicts became more common, most states (including California in 1914) required that new appropriations be registered (25). Texas required, in 1967, that all unrecorded rights holders formally file water rights claims, setting a deadline of two years (31).

Also important in regulatory schemes is how the government handles environmental flows. Historically, water rights have been given to appropriators only, and instream use could not hold a water right. Instead, the state was able to enforce minimal flow requirements, which become especially important during times of drought. Although cutting an appropriator's water allotment without payment is conceivable and occasionally done, it is politically precarious and contrary to the incorrect, yet popular, concept of water rights as property (32, 33). To increase environmental flows, California has opted to establish an Environmental Water Account with which it can purchase water from voluntary sellers (34).

Another form of regulation is with respect to water quality. Too little or too much water use can lead to water quality degradation, altered stream return flows, or decreased groundwater recharge. Coastal cities can also experience seawater intrusion into groundwater aquifers (35). Too much water can cause waterlogging (36, 37). Furthermore, point-source pollution, such as that coming from industrial uses such as paper processing plants, may need regulation to protect downstream users (38).

There are several other concepts used in prior appropriation regimes. An "adjudicated right" is a water right certified by a court process, which makes it easier to trade. A "correlative right" is a water right that is tied together with other rights that have equal priority claims. In times of supply shortfall, all correlative rights holders have their supply decreased proportionately. An "appurtenant right" is a right that is attached to the land and cannot be sold except together with the land.

Another water rights doctrine is that of riparian rights practiced in South Africa and southern Australia, which both have functioning water markets (39). In such a system, water-use rights are historically connected to land adjacent to watercourses. In the case of a shortfall, rights are correlative, in that decreased deliveries are spread to all users without regard to seniority.

Groundwater

Groundwater regulation attempts to combine open public access with management when necessary. Historically, groundwater rights have been attached to the land with an unlimited right to pump from the ground, as is the case in Texas (40).

However, large groundwater withdrawals can result in subsidence and negative effects on neighboring wells. In times of shortage or aquifer stress, legal rulings have found that groundwater-use rights should be treated as correlative rights, legalizing proportional limitations on pumping. In practice, governments and water districts can place restrictions on well spacing, institute a permit process for new wells, or limit the sale and export of groundwater (25, 41).

WATER MARKETS, MODELING, AND TAXONOMY

It is well understood in economic theory that under ideal textbook conditions, markets and trading of a commodity lead to the socially optimal allocation and use of the commodity, regardless of the initial allocation. Hence, starting with rights allocated by a prior appropriation system, the introduction of trading, with the appropriate adjustments for water's nonstandard nature, would lead to the social optimum. Water markets, operating like stock markets, have one price for water; this single price would allocate water according to every agent's demand curve; and the single price would provide the correct benefit to be used in choosing crops and evaluating water conservation technologies. Markets are favored over alternative policies, such as command and control, because they are based on voluntary participation and decentralized coordination through the single price for water (18).

Markets are efficient, but the final allocation and how it is achieved are important policy questions. What crops will be fallowed? Which counties will be sellers and buyers? What will be the external benefits and costs? To answer these questions, economists have built models to investigate the spatial patterns of water marketing and its effects on cropping patterns, economic activity, and water conservation.

Empirical Models of Water Reallocation

In most arid regions of the world, agriculture is highly dependent on the diversion of water resources for irrigation. At the same time, population growth, increased industrialization, and, most importantly, heightened public awareness of environmental benefits from enhancing instream flows are all exerting tremendous pressure on federal and state agencies to reduce these diversions.

An adequate framework for understanding the reallocations of water resulting from these forces requires consideration of several factors, including the following:

- Barriers to trade in water resulting from the water rights regime. Analysis must be flexible enough to consider alternative implementation procedures for water supply cuts, which vary allowable water trading and the regions affected by water supply cuts.
- Heterogeneity in terms of cropping patterns, water availability, and productivity among regions.

- Multiplicity in the responses to water supply reductions, including (*a*) changes in land allocation among crops, (*b*) adoption of water conserving practices, (*c*) use of groundwater, and (*d*) fallowing of lands.

Sunding et al. (42) developed a general modeling approach that incorporates these features. The analysis nests three major empirical models of water use and productivity, specifically applying them to California. The modeling framework provides various measures of economic impacts, including impacts of supply cuts on producers' surplus, producers' revenue, state product, employment, and irrigated acreage. Furthermore, recognizing the large uncertainty regarding producers' behavior and water productivity in crop production, differences between responses in the short run and the long run, as well as data and computational constraints, the empirical analysis does not rely on one comprehensive model that incorporates all aspects of the problem at hand.

The modeling framework consists of a microeconomic model of resource allocation by the irrigated agricultural sector. Optimization is conducted subject to water supply reductions and economic relationships that provide additional assessment measures, including estimated impacts of supply response on employment and gross regional product. The model recognizes the heterogeneity of producers by assuming that production is carried out by a number of microproduction units of various sizes. Such units may be interpreted as farms, water districts, or counties depending on the application and the data available. The model also accommodates barriers to trade and transfers of water between microunits. Indeed, water rights regimes, such as the prior appropriation system and riparian rights systems, restrict trading. One major feature of a policy reform is the extent to which water trading is allowed.

Following theory and empirical evidence, researchers suggest that farmers can respond to reductions in water supply by (*a*) changing land allocation among crops, (*b*) increasing the amount of groundwater pumping, and (*c*) modernizing their water application methods (15, 43–45).

The impacts of reducing agricultural water supplies vary with the planning horizon. The immediate impacts of supply reduction may differ from longer-run impacts because in the short run growers' flexibility is much more limited. Production function parameters, water availability, and costs are subject to much variability and randomness. Ideally, an impact assessment model should be versatile and comprehensive to generate various types of impact estimates. Unfortunately, a model that accounts for heterogeneity among growing regions and all dimensions of grower response to water supply changes does not exist and would be too computationally costly or data intensive to model. Instead, Sunding and coworkers (42, 43) obtain policy impact estimates from three models, each emphasizing a different aspect of agricultural water use. The results of these various models provide a range of impacts within which the actual outcomes are likely to lie.

The models measure the impact of several policy scenarios that have three basic dimensions. The first dimension of the policy change is the level of the water supply available to the agricultural sector. The second dimension is the allocation of the aggregate cutback among water users. In practice, the final allocation of the supply reduction is an open question, depending on which state or federal agency takes responsibility for the decision. Third, the extent of water trading is considered a policy choice.

The three models considered by Sunding et al. (42) are the California Agriculture and Resource Model (CARM), the agroeconomic model, and the rationing model. The CARM was developed to predict profit-maximizing farmers' short-run acreage and production responses to changing market conditions or resource constraints (46). The model divides California into 14 regions that are homogenous in terms of their agronomic conditions, microclimate, and resource costs. Each region has a set of cropping activities that is drawn from a set of 34 crop types and corresponds to the observed annual crop data recorded by the county agricultural commissioners. Each crop has an average yield function, a calibrated quadratic cost function, and Leontief input requirement coefficients for land, irrigation water, nitrogen, fuel, and labor. The resulting model is a calibrated quadratic programming model with quadratic functions for both the regional crop supplies and the statewide output prices.

The CARM objective function can be shown to maximize the sum of producer and consumer surplus from California agricultural crop production. The model has regional constraints on land, water availability, and some crops that are sold through predetermined contracts. The shadow values on these constraints enable the model to generate estimates of the regional opportunity costs of land and water resources in excess of the fixed charges for these inputs. By changing the regional availability of surface irrigation water and restricting the farmer's ability to substitute groundwater, the effects of alternative implementation methods for the water reallocation can be modeled and compared with the outcomes of other models.

The agroeconomic model has the least detail in terms of number of crops and regions but has the most advanced specification of water productivity. This specification allows investigation of the impacts of water supply reductions on irrigation technology choices under alternative scenarios, and it also enables adjustment of predicted water use and technology choices to variations in weather and land quality.

The rationing model measures immediate impacts from changes in water supply policy and relies on the most detailed microlevel data. The basic unit of the rationing model is the individual water district. In California, the water districts are grouped into five regions according to their proximity to various federal Central Valley Project (CVP) facilities and have similar water rights and growing conditions. The model also captures the largest number of crops among the three impact models and is the only model to include both annuals and perennials.

Growers in the rationing model respond to reductions in surface water availability by ceasing production of the crops with the lowest marginal value of applied water. This approach is motivated by the fact that growers have a large degree of flexibility when they make long-term decisions regarding irrigation technology and cropping patterns but have only limited flexibility in the short run. In this respect, the model is based on the "putty-clay" approach to water policy modeling of Green & Sunding (47).

All of the models considered suggest that the incremental costs of reducing agricultural water supplies increase sharply as the quantity reallocated increases. Modeling results suggest that the overall level of the water supply cut is not the most important factor affecting the social cost. Rather, the impacts depend critically on the extent of a water market and, when trading is limited, on how supply cuts are distributed among regions.

Transitioning to Water Markets

These models predict who participates in water trades, how scarce water should be reallocated, and what the hydrological and socioeconomic impacts are. The nature of the transition to water markets is an empirical inquiry that can be answered only with actual data, not models. Critical questions include what water is traded, who trades, and how do communities adjust. The function of actual water markets during nondrought conditions has been studied, among other places, in California (41, 48), Australia (49), South Africa (39), and Chile (10), with markets emerging in the last 25 years in all of these locations. In these four regions, empirical evidence generally supports the idea that water is traded from low-value uses to higher-value uses.

Two of the most important questions in water markets are

- What constitutes a successful water market?
- What rules and institutions are most appropriate to address the transaction costs and potential third-party effects of trading?

Despite the tremendous potential of water trading to increase social welfare, that water is a nonstandard commodity puts special conditions on what a water market should be. To many, the ideal water market would function like a stock market, where stocks are freely traded with few restrictions. Instead, and as suggested by the National Research Council (29), the key hurdle to water trading is to permit as much trading as possible while still addressing the externalities of trading.

Hence, there is an inherent link between tradability of water and the complexity of externalities. Furthermore, the success of a market should not be measured by the number of trades. In Californian, large-scale interbasin trades, which have had complex third-party effects, have required lengthy multistakeholder bargaining (41), whereas the active trading in Australia's Murray-Darling Basin (49) has been easier because of fewer third-party effects. The intuitive argument that one market functions better than the other because it has more transactions ignores differences in trading context. These differences in context and the varied approaches to addressing them are discussed at length below.

The function and dynamics of water market trading need to be better understood. Transfer water can be generated from the implementation of water conservation technology, permanent fallowing, seasonal fallowing, or shifts in crop choice. In the one large California transfer involving the Palos Verdes Irrigation District, fallowing was almost entirely of alfalfa, a low-profit, low-labor crop (41). Most studies are *ex ante* projections of the value of trading that are used to justify changing rules to allow for more trading. More systematic *ex post* studies of the changes in cropping patterns are needed.

Studies have also suggested that trading participation is not based on financial considerations alone. In studying the characteristics of buyers, sellers, and non-traders in Australia, Bjornlund (50, 51) found several differences, including farm size, capital intensity, and family/farm structure, echoing existing research on the heterogeneity of irrigation technology choices (14).

The question of area-of-origin impact is especially important. Models give a static impact, an important measure, but one that ignores adjustment. Of potentially greater significance are the speed with which a community can adjust to an economic shock and the mitigation measures that can ameliorate the transition. Potential mitigating measures include community development investments and job training. The authors are unaware of any empirical articles on this topic.

Types of Water Transfer Arrangements

Aside from permanent sales and short-term leases, many innovative water transfer arrangements exist (52). Callable water-use options allow a city to lease water under specified drought conditions. Water leasebacks, popular in Colorado, are arrangements in which a municipality purchases the right and then leases the water back to agricultural users in nondrought years. Water right priority exchanges can shift the drought-year allocation queue. Banking water artificially stores water, often imported water, in underground aquifers during wet years to be pumped out during dry years. This is not to be confused with water banks, which are brokering institutions.

The 1991 California Drought Water Bank (CDWB) is one of the most studied cases wherein water markets and trading were used for allocation during a drought. Creating a brokered market at a set price, the CDWB purchased 821,045 AF of water though one-year leases of water that was supplied predominantly by crop fallowing and groundwater substitution. The resulting water was available for large-scale interbasin transfer and was credited with averting shortages of critical needs for agriculture and urban use (11).

IMPERFECT MARKETS: TRANSACTION COSTS AND THIRD-PARTY EFFECTS

As discussed above, water markets and trading deviate from an ideal textbook market because of third-party effects and transaction costs, which arise out of water's unique properties. These complications do not preclude the possibility of a well-functioning and socially beneficial water market. Water economists, lawyers, and policy analysts have spent much of their efforts identifying these complications, debating their severity, and discussing how they can be addressed.

Water markets require transferable water rights. Not only do these rights need to be separated from land, but the rights must be clear so that the buyer and seller of a right understand what is being traded. The lack of clarity in property rights creates disputes that must go through costly court proceedings with unpredictable outcomes. One researcher describes the conditions necessary for beneficial introduction of markets succinctly: "the entitlements of all users under all levels of resource availability [need to be] defined" and "third-party impacts (in quality, quantity, time, and place) [need to be] be identified" (9).

Water availability depends not only on the behavior of nature, but also on other users who can affect water availability and water quality or protest a transfer. Rights holders may not use their full allocation every year, leaving water for junior agricultural or municipal users. The behavior of upstream users can also affect the quality of water; return flows may carry additional chemical load. The schedule of releases by dam operators and seasonal environmental constraints affect when water is available for downstream users.

Third-Party Effect: Environmental and Instream Flows

Fisheries and the environment depend on water flow and quality; fisheries and the environment do not typically hold water rights, partly because their use is nonconsumptive. Until recently, instream flows were not recognized appropriative rights in California (41). Environmental legislation and litigation, based on the Endangered Species Act or the Clean Water Act, can supercede and create minimum flow requirements, but the negotiation and regulatory process is not clearly defined, and outcomes are unpredictable (53, 54).

Flows may also be important from a water quality or hydrological perspective. Flowing water provides the environmental service of pollution dilution. Water use can also introduce problems of water salinity and drainage, as was the case in the Tulare basin of California's Central Valley (52, 56, 57). Trades out of this basin could have a positive drainage externality. Saltwater intrusion can result when net withdrawals from an aquifer are too high (47).

Third-Party Effect: Other Rights Holders and Downstream Use

Other rights holders may also be affected by water trading, either by a decrease in quantity or by some other effect. The most-used example is that of downstream users. In one case, a downstream irrigation district protested an upstream agricultural trade. The court-decreed resolution limited the transfer amount to existing agricultural consumptive use (18). The main drawback of using consumptive use as a benchmark is that heterogeneity, such as local soil conditions, can greatly affect water use, causing inaccurate estimates based on average consumption. In fact, one study found that estimated consumptive use, based on acres planted multiplied by estimated water use by crop, exceeded total water use in several irrigation districts, casting doubt on the use of estimates (57).

There may be other, potentially complex, effects on downstream users. In Chile, a paper mill generated water pollution, and the river's flows were sufficient to dilute the pollution by the time it reached a downstream municipal water supply. Proposed construction of a dam and diversions upstream would have decreased the flow such that the water reaching the municipality would have been too polluted (10). Dams can also affect the timing of water releases: dam operators prefer to release water in the winter, when energy prices are high, which is in direct conflict with farmers who need water during the growing season (10).

Socioeconomic Area-of-Origin Effects

There are multiple forms of socioeconomic area-of-origin effects. The first effect, which is intensively studied and modeled by economists, involves the forward and backward linkages to other county activity. Decreased farm activity eliminates farm employment and decreases sales for supporting businesses. The modeling of regional outcomes is quite central to policy evaluation, the design of appropriate mitigations, and the political sensitivity of a trade.

A second effect is the potential breakdown of the local community. Decreased economic activity erodes the tax base, and a smaller base of farmers must pay the fixed costs for maintenance. If farm activity declines substantially, supporting businesses may close, making it more difficult for the remaining farmers. Vacant lands may develop noxious weeds or soil erosion and may create the psychological atmosphere of a city in decline, which becomes a self-fulfilling prophecy (25, 29, 58, 59). The existence of area-of-origin effects is not debated, but the severity of the effect is highly contested.

Third-Party Effect: Groundwater-Surface Water Interaction

During the 1991 CDWB, 33% of water traded came from groundwater substitution. Instead of fallowing, a farmer or irrigation district was able to trade entitlements to surface water and pump water for irrigation. Groundwater is often a limited resource; overextraction leads to declines in the water table and increased pumping costs. Monitoring programs were used to ensure that local groundwater basins were not adversely affected. The short duration of the bank's existence curtailed any significant impacts (60).

Surface water recharges groundwater aquifers, a fact well known to economists and water engineers but not integrated well into water law. Laws in many states treat groundwater and surface water law differently, compounding the incomplete understanding and fragmented management of many underground aquifers. As a result, groundwater trading becomes difficult.

One type of transfer, groundwater banking, exploits the groundwater-surface interaction by artificially recharging aquifers and then using them as underground storage reservoirs. Southern California and central Arizona have carefully addressed the legal questions of groundwater rights before ultimately implementing groundwater banking projects (34, 61, 62).

Legal Costs

Conflicts arise in water trading because of competing claims or claims of third-party injuries. Subjecting each conflict to a court or administrative hearing would be a high-cost method of resolution. Establishing clear criteria for approving transfers and predictable procedures for resolving third-party compensation claims would lower the cost of resolution (63).

The ease of transfers varies greatly. As discussed above, the broadness of the transfer approval criteria (i.e., regulatory procedures, what third-party claims are valid, and who has legal standing to protest) increases the transfer difficulty. Another major issue is whether the rights have been adjudicated. In the lower Rio Grande region of Texas, adjudication of competing river basin claims took 15 years to resolve (31). Although costly in time and money, the resulting claims are clear and precise, precluding legal disputes and generating an active regional, intrabasin transfer market. In contrast, interbasin transfers bring a broader review for third-party impacts, explore uncharted legal ground, are more controversial, and are hence less common. Even without significant third-party effects, three of California's larger transfers took several years to negotiate (41).

The absence or advance settling of third-party effects is a common feature in active regional water markets. Shares in the Colorado–Big Thompson Project area are largely protected from third-party claims (12). The lower Rio Grande has court-mandated correlative rights, and because the subbasin drains directly to the ocean with no groundwater effects, there are no downstream rights holders to file claims (31).

Explicit Barriers to Trade

In the United States, one of the greatest barriers to water trading is federal water. Of 42 million AF used annually in California, 7 million AF is from the CVP and subject to the rules of the U.S. Bureau of Reclamation. During the 1991 California drought, the CVP water was excluded from water trading by the federal authorities who had a long-standing policy of not allowing trades out of the project. In 1992, the CVP Improvement Act was renewed, after considerable political maneuvering, with reforms that allowed trading with highly restrictive conditions (3, 64).

In individual irrigation districts, trading of water rights by individual farmers is constrained by the district. In California, water rights are held by farmers, although the district typically holds the permit for physical diversion or the contract for State Water Project deliveries. Water districts, which have independent, elected governing structures, often preclude their members from engaging in potentially profitable out-of-district trades. In current practice, out-of-district trades require careful negotiations on the level of the district governing body (26, 65).

Infrastructure Costs and Constraints

Trading cannot occur if water cannot be transported. In California, considerable expense has gone into the construction of the State Water Project (linking northern and southern California) as well as the Colorado River Aqueduct (linking the Colorado River to Los Angeles). Even with adequate infrastructure, the control and constraints of infrastructure can complicate trades. An interesting situation occurred in 1998 when a San Diego-Imperial Irrigation District deal needed to transport water through the Metropolitan Water District's infrastructure. The Metropolitan Water District initially quoted a rate of $262 per AF for wheeling, or transporting, the water. This was about three times what San Diego was expecting and effectively doubled the purchase price (4).

New infrastructure is often needed to facilitate trading. In California, many central coast cities are not adequately connected to the state's extensive water distribution network. In California, water transfers from northern California to central California are currently limited by ecological constraints of the San Francisco Bay delta (53, 66). Infrastructure costs are substantial and may considerably decrease the potential gains from water trading.

Political and Social Barriers

Even when all third-party effects are addressed adequately, there exist political and social barriers to water markets. Considering that water markets are meant to be more economically efficient, the gains from the transition should be sufficient to make all parties at least as well off. However, deciding on a distribution of gains is quite difficult. In practice, multiple stakeholders (often framed as farmers vs cities) must agree on the rules governing trades and have trade-enabling laws passed (3). One concern raised has been that all the gains accrue to the landowner at the expense of tenant farmers. The complications for developing countries (where water trading can be seen as conflicting with social equity, basic access to water, and the livelihood of poor farmers) frame the development of effective water trading institutions (67, 68).

FOUR CURRENT DEBATES

Four current arguments against water trading are central to current research and debate.

Argument 1: Water Markets Mean Reallocation from Agricultural to Urban Uses

A popular perception of water markets is reallocation from agricultural to urban uses. In practice, the evidence is mixed. During the 1991 CDWB, agricultural transactions comprised 20% of its temporary water sales. In the Colorado–Big

Thompson project area, approximately 26% of water trading was within agriculture. A recent report on a comprehensive data set of California transfers from the 1980s through 2001 shows a mix of buyers. In 2001, a somewhat dry year, about a third of the water transfers were to the environment, and about one fifth of the transfers were to municipal and industrial users, with the rest going predominantly to farmers (69). Although these numbers do imply significant urban transactions, they demonstrate that water reallocation within agriculture can also be quite significant.

Trading in the Murray-Darling basin of Australia demonstrates the significance of trading within agriculture. There, urban growth centers currently have adequate supply or are physically separated from the basin, hence trading to urban uses is virtually nonexistent. Despite this, an active market exists in reallocating water within agriculture, with the flow of trade from low-value grain to higher-value crop/wine producing areas (70).

There are several reasons why large agricultural-to-urban transfers of water are not more prevalent. Lack of infrastructure and high conveyance costs limit transfers to growing urban areas. Furthermore, operational rules often limit transactions. In the United States, federal water trading rules have, until recently, explicitly limited trade as well as discouraged it by prohibiting profit making (64). Transactions within agricultural districts do not generally require approval and are thus much easier than heavily scrutinized, interbasin, agricultural-to-urban transfers. Many counties in California have moved to restrict water exports, especially of groundwater (65).

Some large agricultural to urban transfers have occurred. Los Angeles purchased the water rights of Owens Valley between 1905 and 1934. The Imperial Irrigation District negotiated two long-term transfers in 1988 and 1998, transfering 100,000 AF and 200,000 AF, respectively, to southern California water districts. This water was generated by canal lining and fallowing. Urban purchases have also been significant in Texas' Rio Grande area, northern New Mexico, and central Arizona (29, 40).

Argument 2: Transfers Result in Large Economic Losses for Areas of Origin

Water trading is easier and more prevalent within basins, but researchers have long identified potential gains from out-of-basin trades. Concerns over area-of-origin impacts are frequently raised.

This perception began with the infamous Owens Valley transfer, whereby Los Angeles secretly purchased the water rights of an agricultural area between 1905 and 1934. As a recent reanalysis of the transaction emphasizes (71), sellers were paid more than their land was worth agriculturally but much less than the buyer's value of water. This distributional asymmetry contributed to the negative legacy of the transfer. Ignored in the analysis, but perhaps more significant, are the effects on third-party businesses and employment. The transfer ended irrigated agricultural production in the area and had widespread community effects with no gains to nonlandowners. The Owens Valley transfer is not representative of most transfers.

Local effects of water exports are real, but results depend on the response of water sellers. An *ex post* evaluation of the CDWB concludes that statewide transfers increase total welfare, but locally, there were some negative effects (72). More recent calculations for the Central Valley predict an impact of $170,000 of net income loss and eight job losses per thousand AF traded. This figure was derived from modeling a hypothetical transfer of one million AF out of agriculture (73). The modeling presents a static one-period picture; over time, areas will adapt in ways similar to the adaptation of cities to industrial plant closures (12).

The net local effect is not necessarily negative. If farms are temporarily fallowed, impacts may be short lived, as evidenced by the CDWB. For longer-term transfers, the local effect of water trades largely depends on the response of the farmers selling water. Theory suggests that "income flight" out of the area of origin would lead to negative local effects, whereas income reinvestment could lead to local welfare improvements (74).

The area-of-origin impacts can be accommodated by several measures. First, compensation can be provided, as was done by the creation of mitigation funds for some recent California projects (65). Cities can plan for the transition by diversifying the local economy or other coping mechanisms, as was the case with the city of Blythe, California (41, 58). Others argue that negative transitions due to transfer are realized slowly and that change is an inherent risk of doing business, so the need for compensation may be limited (75). Second, caps on traded volume in a given year have been advocated and adopted. In Australia, there is a nationwide transfer cap. Individual irrigation districts, which hold effective veto power of transfers, also institute caps (70). A suggestion from the early literature of a 15% cap on transfers seems reasonable (72). Third, to address local government funding concerns resulting from urban purchase of farms and subsequent fallowing in Arizona, water purchases make in lieu municipal tax payments, and the state government can adjust local government funding to account for water trade effects (26, 76).

Argument 3: Interbasin Trade Should Be Prohibited Because of Large Hydrologic Effects

Many raise concerns about interbasin trades and their effect on hydrology. Incomplete understanding of water systems limits the precision of mitigation and management, but institutions can be formed to deal with hydrological concerns.

Groundwater is an area of particular interest. The California Department of Water Resources uses a concept called "paper water," which is "water proposed for transfer that does not create an increase in the water supply" (7). California law is vague about transfers of water that otherwise would percolate to underground aquifers (which can be pumped later), but the Department of Water Resources generally considers such water to be paper water. Water trading obviously affects groundwater recharge, but the change is not necessarily negative. Using an integrated hydrological-economic model, researchers concluded that water trade could lead to both increases and decreases in groundwater nitrate concentrations (38). Of more practical concern, groundwater overdraft can result in seawater intrusion, which is of great concern for several coastal California cities (35). Insofar as coastal imports substitute for coastal groundwater pumping, trading can be hydrologically beneficial.

A behavioral hydrological consequence is the trading of previously unused water. In California, paper water includes water rights that are not always fully used. In Australia, such rights are termed "sleeper rights," and the activation of such rights means a larger use of water than in previous years.

Mitigations that can address these hydrologic concerns include restricting trade to consumptive use and effective joint regulation of groundwater and surface water. However, restricting trade to consumptive use has technical complications, such as the spatial and temporal variation of consumptive use, and would still need to be adjusted on a case-by-case basis. Court and administrative procedures to protect against adverse groundwater and return flow effects produce unpredictable ad hoc results. Interbasin trades currently require substantial negotiation and face potential litigation but can result in welfare-improving trades.

Argument 4: Water Is a Public Good and Should Not Be Subject to Market Forces

Whether water should be treated as a commodity is perhaps the most contentious debate within the water trading literature. The bulk of this review and the water economics literature has been in support of water markets (with the general message that, under appropriate preconditions, the creation of voluntary water markets can achieve the social optimum of economic efficiency). This viewpoint emphasizes the private good qualities of water. Critics have pointed to three arguments emphasizing the public good qualities of water.

1. Values used in defining economic efficiency are flawed. Values based on willingness to pay are skewed against those lacking ability to pay, the poor. Market mechanisms emphasize the need to reallocate to high-value uses, and most discussions skip over the need for water management to provide clean water, along the lines of the UN Basic Water Requirement, to all people (9).
2. Inadequate attention is given to preconditions needed for effective water markets. As discussed above, market advocates are concerned about third-party impacts. The environmental economics literature has a long tradition of studying externalities, emphasizing the need for effective mechanisms to solve the resulting water conflicts. Conflict resolution depends on laws and institutions. In the western United States, state regulatory agencies or special water courts provide mechanisms to address these impacts (25), but not all places provide effective mechanisms (10).

3. The use of economic efficiency as the sole criteria is incorrect. Integrated water resource management balances three principles: economic efficiency, social equity, and the environment. The tendency within economics is to treat the latter criteria as part of economic efficiency, introducing external constraints on the market. However, the social equity of small farmers and tenant farmers (who do not own the water rights) can be seen as inadequately addressed. The market context accounts for environmental externalities only insofar as the institutional rules can address them. In the United States, with the Environmental Species Act, pollution regulation, and the participation of multiple stakeholders, institutions do integrate environmental values into the regulatory framework. In Chile, in contrast, government jurisdiction is unclear, and environmental regulatory power is difficult to apply; the environment is effectively an institutional afterthought to strong property rights (10).

The Dublin Principles, formulated at the 1992 International Conference on Water and the Environment, established a common understanding of water's scarcity and the importance of managing it as an economic good, but only as one of its four principles. In the western United States, where agricultural, urban, and environmental stakeholders are actively engaged in developing the operational rules for water management, appropriate institutions have developed. One author, indirectly remarking on the problems with Chile's laissez-faire water law development, cautions (10), "Countries and governments should not make the mistake of thinking that they can implement reforms in two steps, by first adopting a free market approach to water economics as a straightforward initial step, and then turning their attention to the remaining problems of the IWRM and water governance. At that later point their hands will already be tied by a definition of property rights that has major political and institutional implications."

The end result is not to invalidate the usefulness of water markets. Instead, the criticism highlights that water markets are not sufficient to address all problems and that attention must be paid to water's unique and public good characteristics. Those who caution against haphazard market formation are not necessarily opponents; once basic uses of water (human and environmental water needs) are met, water markets are an efficient mechanism for dealing with the scarcity of the remaining elective uses of water. The prognosis is that water markets need appropriate, effective institutions, and models that recognize the public good qualities of water, incorporate transactions costs, and address third-party externalities.

CONCLUSION

Although the authors endeavored to make broad comparisons between currently functioning markets, that task was beyond the scope of our time and ability. In particular, it became apparent that each area had unique circumstances that framed the development and function of water markets. Instead of a cross-country synthesis, our aim has been to present an analytical framework that recognizes and models the potential for water markets to address the problem of water scarcity while identifying the myriad complications of transaction costs and third-party effects. Considerable progress has been made in the literature as markets have moved from theory to practice. Although we have focused on the western United States, and California in particular, we have tried to cite works on southern Australia (49), South Africa (39), and Chile (10). Rather than cover other areas haphazardly, we punted and leave to other researchers the important task of making cross-country comparisons and understanding the link between an area's historical context and its institutional development of water markets.

Considering that supply augmentation was the main strategy through the 1970s, water markets are less than 30 years old. For droughts in the short term and urban growth in the long term, the need for trading to efficiently allocate water will only grow. Effective, appropriate water markets will only emerge with the development of laws and institutions that address transaction costs and third-party effects. Combined with water conservation on the demand side (77), water markets are an integral option for allocating scarce water.

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