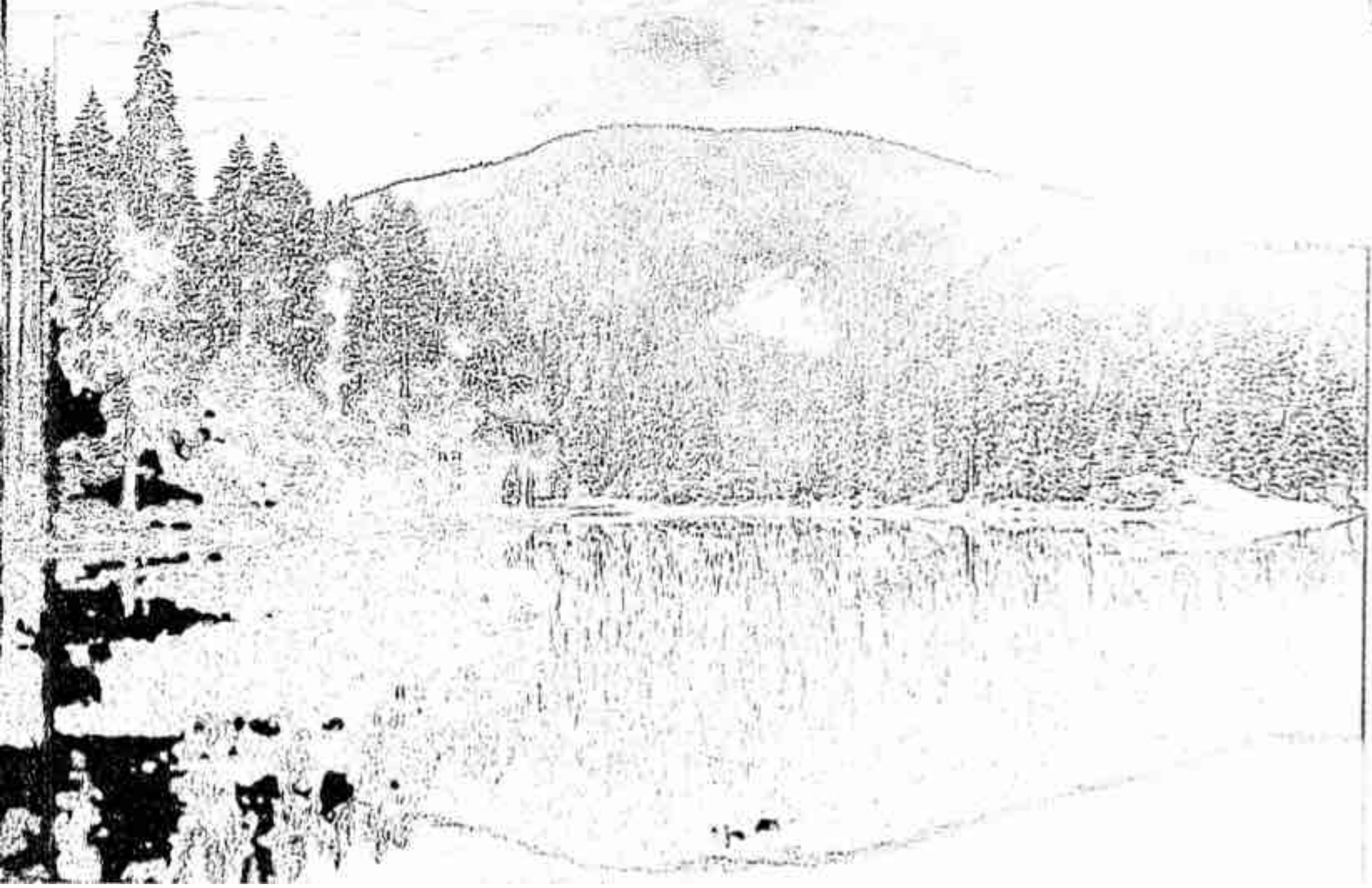
Handbook on the Economics of Natural Resources

Edited by Robert Halvorsen • David F. Layton



16. Water institutions and the law of one price

Eric C. Edwards and Gary D. Libecap

16.1 INTRODUCTION

This chapter examines the economics of the water rights and markets in the US West. This is the region of North America where water supplies are most limited in face of rapidly growing demands. The striking feature of water markets is how unlike those for other commodities they appear. In particular, the law of one price does not hold. Agricultural commodities, for instance, empirically do not have systematic price differences that persist over time (Baffes 1991). This is not the case for water. In water markets, municipal and industrial users typically pay much more than do agricultural agents to acquire and use water.

Examples abound that demonstrate observed price differences that are not immediately explained by properties of the water or infrastructure. Price disparities exist in local water markets like Nevada's Truckee Basin, where the median price of 1025 agriculture-to-urban water rights sales between 2002 and 2009 (2008 prices) was \$17685 per acre-foot (AF), whereas for 13 agriculture-to-agriculture water rights sales over the same period the median price was \$1500/AF.[1] In another market, the South Platte, Colorado, the median price for 138 agriculture-to-urban sales between 2002 and 2008 was \$6519/AF as compared to \$5309/AF for 110 agriculture-to-agriculture sales. These prices are much closer, but they are not typical. In light of this information, what constrains water markets today? The cost of water infrastructure can be high, yet Los Angeles has constructed over 400 miles of aqueduct to move water from the east side of the Sierra Nevada Mountains to the Los Angeles Basin. After the costs of construction, negotiation, and payment for the water rights, and environmental mitigation, Los Angeles still has gained enormous surpluses (Libecap 2009).

The institutional structure surrounding water rights and markets helps to explain why the law of one price does not prevail. Water demonstrates Coase's (1960) point that if transaction costs are positive (and in the case of water very high, for reasons that we explore), then the initial distribution and nature of water rights has important long-term allocative implications for the economy. Decisions about water are often made through judicial, legislative, and bureaucratic processes without direct price and cost considerations. This situation creates both challenges and opportunities for economists in research on water and in promoting more efficient water distribution, investment, and use.

This chapter examines how property rights institutions play a key role in explaining why the distortions seen in limited water markets persist. We begin in section 16.2 with evidence on the continuing price disparities among various water applications to illustrate the problem of misallocation. These disparities are more difficult to demonstrate than might otherwise appear. Generally, contemporary water markets, including permanent water rights sales and short- and long-term water leases, are local with trading confined within water basins and sectors (among adjacent irrigators, for example). Many informal exchanges are not recorded and there are few centralized registries of water transactions in western states. Typically, exchange outside of a water basin is limited, and voluntary transactions to move water from agricultural to urban use involve high transaction costs, as we describe below. And there is virtually no private water trading across state boundaries. As a result, price comparisons are difficult to assemble because of segmented markets, limited comparable observations of trades within and across sectors, differential conveyance costs, diverse regulatory regimes, and variation in quality. In section 16.3 we examine the trade-off in defining property rights to water in terms of the costs and benefits of increased ability to capture rents. The focus is on surface water where stream flows raise measurement, bounding, and enforcement costs (Barzel 1982), but where increased demands are raising the benefits of more precise definition of water rights (Demsetz 1967). Section 16.4 describes the 'appropriative doctrine' that underlies most western water rights. The major challenges associated with it are discussed, including uncertain water flows affecting amounts available to each user. Appropriative rights are conditional upon beneficial-use requirements (the 'use it or lose it' rule), and any exchange involving shifts in the timing, nature, and location of use are subject to the no-injury rule affecting third parties.

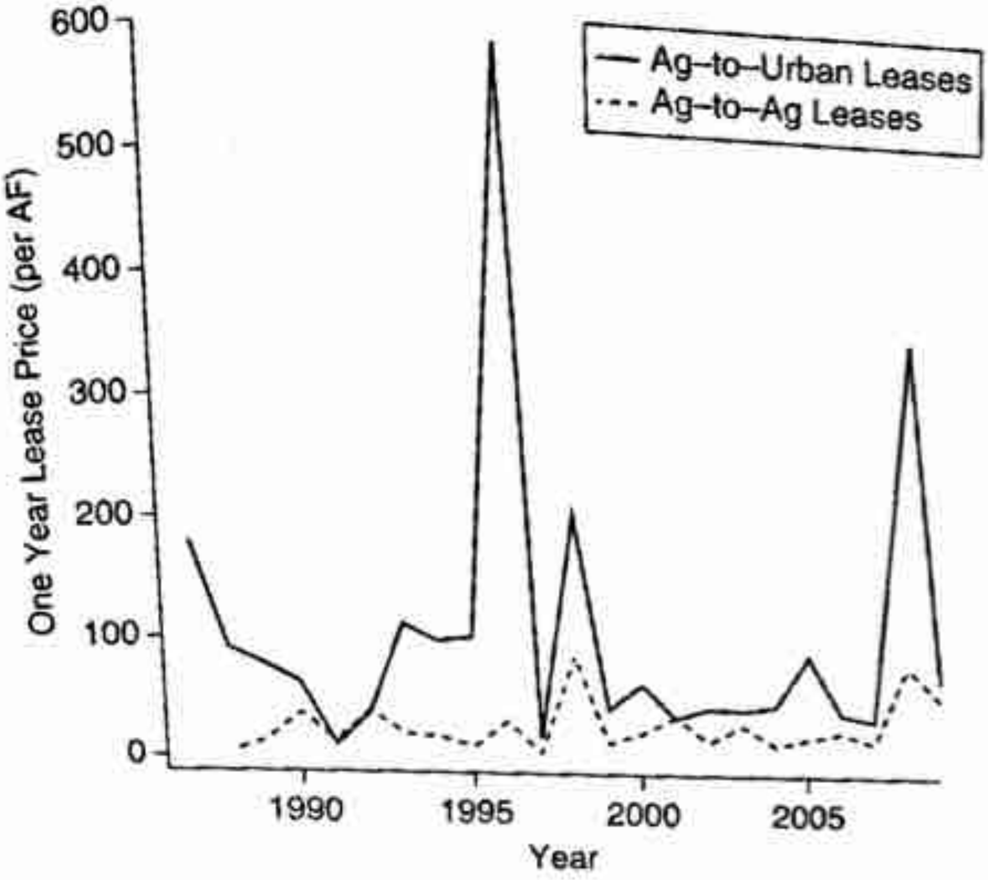
Section 16.5 examines water supply organizations and their impact on water markets. Irrigation districts are the focus because they control as much as 80 percent of the West's water and because their varying governance structures and water rights arrangements affect the ability of members to exchange water out of the district. The experience of two irrigation districts in California, the Imperial Irrigation District (IID) and the Palo Verde Irrigation District (PVID) highlights how the governance structure and vagueness of property rights can raise the transaction costs of trade. Both of these irrigation districts receive Bureau of Reclamation (BOR) water. Another BOR project, the Colorado–Big Thompson (CBT) is examined in some detail because of its unique water rights structure: shares of the annual allowable appropriation that supports the most active water market in the West. Details on water trading within the CBT are provided. Section 16.6 outlines the welfare losses from limited water trading and provides illustrative data that indicate the gains from the greater trade of small amounts of water from agriculture to urban use. Section 16.7 outlines the potential for innovation in the structure of water rights from the current appropriative system to shares of a variable stock. The analysis highlights the aggregate benefits, but identifies which parties are likely to be made worse off by such rights transformation. Concluding remarks follow in section 16.8.

16.2 WATER RIGHTS MARKETS: TRENDS IN THE WESTERN USA

Perhaps the most important aspect of water, relative to other economic goods, is that there is a lot of it and humans use a lot of it. This means the value of water depends on its scarcity relative to demand at a more local level than for other more mobile commodities. While in wet regions water can be abundant, in drier regions the value of the available water exceeds the cost of supplying it, referred to as scarcity value. Users may have low costs of extraction, but efficiency dictates that they make decisions based on the value of the water in various applications, not on the cost of extraction. An active water market provides this incentive, allowing low-value users to capture some of the scarcity rent of their water right through sale or lease. How well a market does this can be measured by assessing how well the law of one price holds. In water markets, we take this to mean that two water rights with the same seniority, quantity, quality, and location should be priced the same.

Much of what is known empirically about water markets in the US West comes from the monthly water transactions recorded in the trade publication *Water Strategist*, which was published from 1987 to 2010. This dataset provides a snapshot through time of water trading throughout the West, and supports assertions that the law of one price does not prevail: agriculture-to-agriculture trades are consistently transacted at lower prices than agriculture-to-urban trades.[2]

Figure 16.1 shows that since the early 1990s, agriculture-to-urban leases have been traded at higher prices on average than agriculture-to-agriculture leases.[3] Year-to-year lease and sales comparisons by state are

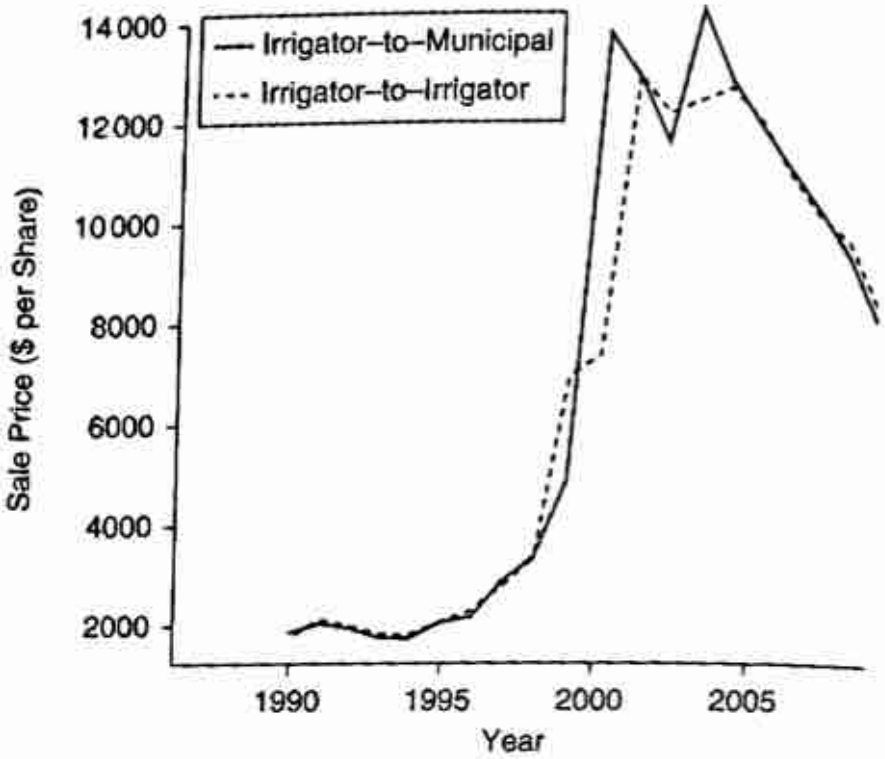


Source: Authors' calculations from Bren School Water Transfer Dataset. Dataset is available at http://www.bren.ucsb.edu/news/water_transfers.htm.

Figure 16.1 Price comparison of mean agriculture-to-agriculture and agriculture-to-urban one-year leases in the Western US

difficult to make due to the limited number of transfers in the dataset, but the price pattern is consistent with state averages over time. These data provide only a limited empirical account of western US water markets, and many other studies have used *Water Strategist* data to explore the factors affecting water prices (see, e.g., Brookshire et al. 2004; Brown 2006). An important shortcoming of the *Water Strategist* data is its under-representation of trades within agriculture. Brewer et al. (2008a) examined other research on water trades in California to assess the completeness of the *Water Strategist* data, finding some indication of missing trades. Further analysis hinges on the ability to obtain more systematic data.

In contrast to the trends observed throughout most of the West, the law of one price does seem to appear in trade data from the Colorado–Big Thompson project. Figure 16.2 shows the trend in irrigator-to-municipal and irrigator-to-irrigator sale prices. Howe and Goemans (2003) assert that there are three reasons why CBT is more efficient than other water markets: (1) rights are homogeneous shares of total available water; (2) there is no trade restriction to protect return flows; and (3) transfers only require the approval of the district board, not a water court. That these



Source: Authors' calculations from Bren School Water Transfer Dataset. Dataset is available at http://www.bren.ucsb.edu/news/water_transfers.htm.

Figure 16.2 *Colorado Big–Thompson mean irrigator-to-municipal and irrigator-to-irrigator sale price comparison*

particular characteristics have important efficiency implications highlights the need to understand the institutional context of water markets. It is largely such institutional factors, not geographic or economic traits, that dictate the behavior of the CBT relative to other water markets such as the Central Valley Project in California (Carey and Sunding 2001).

In many states with less secure water property rights, leases tend to occur much more often than do sales (Brewer et al. 2008a). From 1987 to 2009 the *Water Strategist* dataset includes 420 leases and only 47 sales in California. Leases, particularly short-term leases, allow water to move with fewer regulatory barriers and therefore have lower transaction costs than sales (Brewer et al. 2008b, p. 192). The prices of one-year leases and sales can be used to calculate the implicit capitalization rate (ICR) that provides a measure of property rights security because in a competitive market the one-year lease price should equal the expected one-year economic rent (Grainger and Costello 2011). Table 16.1 shows the average ICRs for two states: Colorado, with a high number of sales; and California, with a high number of leases. California ICRs are much higher, demonstrating the higher relative value placed on leases, likely due to regulatory restrictions and associated transaction costs of permanent water rights sales.

Table 16.1 *Implicit capitalization rate comparison*

Acquirer	California	Colorado
Municipal	13%	0.8%
Agricultural	4.5%	0.9%

Source: Brewer et al. (2008a, p. 102).

In the US West there is increasing pressure on water allocation institutions. Climate change, population growth, and an increase in demand for *in situ* environmental use all likely require a change in water allocation. Many calls for increased instream environmental flows tend to be met with mandates and court rulings – like the public trust doctrine – which tend to incur a higher cost and take longer to resolve than market solutions (Brewer and Libecap 2008). Climate change projections indicating greater uncertainty in water availability coupled with projected population increases in arid areas like Southern California and Arizona point towards a future need for greater flexibility in trade and a possible revision of water rights (Libecap 2011). In the next section we explore why this is not a straightforward proposition.

16.3 RENT, COSTS, AND PROPERTY RIGHTS

In this section we examine the evolution of water rights to determine why water markets appear to be so limited. In western states, individuals do not own water as they might own land. This in itself is suggestive of the special nature of water. The state owns the water, which it holds in trust for its citizens. Individuals hold usufruct rights to the water, subject to the requirement that the use be beneficial and reasonable, and to oversight by the state in monitoring use and water transfers to ensure that they are consistent with the public interest. Accordingly, there is a broad regulatory framework for water trading so that western water rights potentially have less protection and are more fragile than most other property rights (Sax 1990, p. 260; Gray 1994, p. 262).

In general, property rights outline expectations for resource use, investment, and exchange by owners (Libecap 1989; Barzel 1997). Ownership can be private, group, or held by the state, and each arrangement involves different transaction costs of decisions over resource use and trade. Property rights require measurement, bounding, and enforcement. Measurement costs are affected by the physical nature of the resource – the degree to which it is observable, stationary, and excludable. Bounding costs depend not only on measurement, but also on access control or excludability. For example, Libecap and Lueck (2011) analyze the conditions under which the rectangular demarcation of surface land as compared to irregular demarcation provided net benefits. Enforcement costs depend upon measurement and bounding, as well as the value of the resource. Observable, stationary, clearly and uniformly demarcated assets can be enforced at lower cost against use by non-owners. All else equal, higher-valued resources invite entry, and hence have higher enforcement costs.

Direct property rights to non-excludable resources such as the atmosphere do not exist because of extreme costs of measurement, bounding, and enforcement. For that reason, rights-based regulation of the use of the atmosphere, such as cap-and-trade, also involves usufruct rights, tradable rights to pollute. Property rights to surface water, however, are measureable, boundable, and enforceable, although at higher cost than for land. Accordingly, whether water rights exist depends in part on the potential value of water relative to the costs of rights definition.

If property rights are fully defined and enforced, owners have incentives to maximize resource values in use, investment, and trade and thus capture the full resource rent. Moreover, there is no third-party impairment in use or exchange. These conditions arise when transaction costs – the costs of defining and enforcing property rights (Allen 2000) – are zero. As Coase (1960) argued, the distribution of property rights under these circumstances does not matter for efficiency, but does affect the distribution of income and wealth. In reality, transaction costs are positive (Coase 1960, p. 15; Williamson 1975), and accordingly, a focus on transaction costs helps to explain why water rights and markets are limited and the law of one price does not hold. As Demsetz (1967) outlined, investment in lowering transaction costs occurs when there are net benefits from doing so; when the potential increases in value from new applications, investments, and trade exceed the added costs of measurement, bounding, and enforcement. This relationship has been documented for land rights (Anderson and Hill 1975), hard-rock minerals (Libecap 1978), and petroleum (Libecap and Smith 2002). In this regard surface water is not unique. But flowing water has higher measurement, bounding, and enforcement costs than land, and historically lower value than hard-rock minerals and petroleum. Because of this, water rights have not been precisely designated and often 'paper rights' exceed wet water rights (Hanak 2003, p. 9): water is overallocated.

It is useful to lay out the parameters that affect the definition and enforcement of property rights. The likelihood of the property rights definition being low, medium, or high is determined by the present value of

Table 16.2 *Factors influencing the costs and benefits of property rights definition*

Transaction costs*	Benefits of property rights
Bargaining for design and implementation	The property right as collateral, ability to invest, change nature of use, exchange via sale or lease, spatial reallocation, and intertemporal transfer
Monitoring, detection, and enforcement	Maintain incentives for use, investment and exchange, and avoid competitive rent dissipation
Information about alternative uses and trading potential	Identify potential private capital gains or improved provision of public goods
Bargaining to exchange property rights	Reallocate to implement new private and/or public uses

Note: *From Coase (1960, p. 15), McCann and Easter (2004).

rent available and costs of defining and enforcing the property right. Shifts in the present value of definition (higher potential values, lower measurement, bounding, and enforcement costs) change the probability of observing a change in property rights definition (Libecap 1978).

For more precise property rights to emerge, rents captured through clear property rights definition, as outlined in the right-hand column of Table 16.2, must exceed the transaction costs outlined in the left-hand column. Until recently, in the US West surface water supplies were relatively abundant, compared to demand, and there was little change in water institutions or formal trade. Lost rents from incomplete rights were not large relative to additional costs. As demands have increased, the parameters have shifted to support more definite water rights, but the slate is not clean. Adjustments in water rights and water supply institutions, such as irrigation districts, occur within the framework of existing arrangements and the expectations they define. Institutional change to promote greater market transactions raises uncertainty for some existing rights holders, who may not see their position improved, even if there are aggregate benefits (Libecap 2011). Further, there is concern that public goods will not be supplied with greater definition of private rights (Samuelson 1954). We explore these issues in sections 16.4 and 16.7.

Figure 16.3 shows how path-dependence, based on historical water rights institutions, could affect subsequent adjustments in property

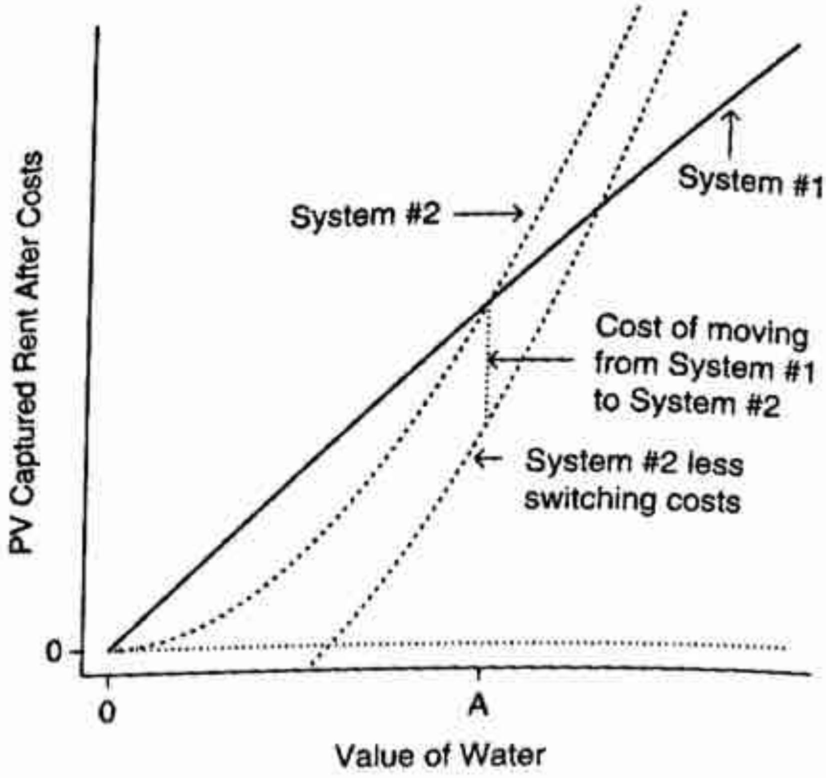


Figure 16.3 Rents captured from property rights and path dependence

rights. On the vertical axis is the present value of rents minus the costs of defining two different property right regimes as derived from entries in Table 16.2. System 1 is optimal when water values are low. It involves a looser definition of water rights with lower measurement, bounding, and enforcement costs. Exchange is more costly under System 1 because the unit exchanged is vague, but at low water values trade is limited. The pattern of net rents offered by this rights system is illustrated conceptually by the straight line rising from the origin. System 2 has a more precise rights definition, but requires more upfront investment in measurement, bounding, and enforcement. Its pattern of net rents is illustrated by the dashed line in the figure, also rising with the value of water. As shown, it is optimal, all else equal, beyond water value A. Even so, rights are unlikely to adjust quickly from System 1 to System 2. The third line shows the net rents of System 2, accounting for the cost of switching from System 1. Even though the new rights structure in System 2 provides greater net rents at water values greater than point A, the transaction costs of adjustment are high, and as a result the move to the new system will not occur until the value of water is much greater and the net rents of System 2 are large enough to offset higher transaction costs. This has important implications for market exchange if it is inhibited by the historical existence of rights System 1.

16.4 THE APPROPRIATIVE RIGHTS DOCTRINE

16.4.1 Overview of Western Water Rights

Following the same property rights allocation practices used for western agricultural land and hard-rock minerals, prior appropriation rights to water are assigned through first possession, or 'first-in-time, first-in-right' (Lueck 1995; Kanazawa 1998; Libecap 2007). Appropriative water rights grant possessory rights to a fixed quantity or flow of water, usually measured in cubic feet per second (cfs), for diversion from a stream, based on the date of the original claim. Those with the earliest claims or senior rights have the highest priority and subsequent claimants have lower priority or junior rights. Diversions are accommodated by rank so long as there is sufficient stream flow. Accordingly during drought, water is progressively rationed by priority of right, and junior diversions may be halted.

Diversion is a low-cost method of allocating water and was efficient when overall consumption was less than stream flow. It does not require information on the total amount of water available, as would be the case if rights had been defined in terms of shares of the total, or information on consumption if rights had been tied to consumptive use (Smith 2000). Monitoring costs are reduced because diversions can be observed. With increases in demand and total diversions equal to or exceeding stream flows, defining appropriative rights to avoid third-party effects and promoting water exchanges requires additional information: total stream flows, rights seniority, diversions, consumption, and position on the water system.

Appropriative rights are not tied to the land. Therefore they can be sold or leased for use elsewhere, creating a basis for water markets and security for investment in water delivery infrastructure, agriculture, and other endeavors. Appropriative rights require that water is put into beneficial use and that these uses inflict no injury to third parties. Beneficial use emerged as a low-cost way of determining if there is excess water to be appropriated by new claimants. Beneficial use, however, increasingly contributes to economic waste in the absence of water markets as rights holders devote water to low-value approved applications. They do so to maintain ownership but neglect higher marginal-value uses that may not be considered consistent with the mandate.

Under prior appropriation there is a critical interdependence among diverters from the same water source with different priority rights. As much as 50 percent of senior diversion is not consumed by plants or evaporation and flows back to the stream or percolates down to the aquifer to be available for subsequent users (Young 1986, p. 1144). During times of drought when natural stream volumes are diminished and senior appropriators have priority of use, junior appropriators are especially dependent upon these return flows. They bear most of the downside risk of drought. Actions by senior rights holders to change the location, nature, or timing of use can affect water consumption and thereby influence the amount of water released downstream. Accordingly, water trading from agriculture to urban uses that involves export out of the basin and thereby reduces return flows can impair third parties and is subject to state regulation to reduce damage to junior diverters.

Applications for transferring rights are filed with the relevant state regulatory agency for approval. The applicant specifies the location and amount of water, the duration of the contract, the timing of the exchange, type of water right involved, consumptive use, and possibly hydraulic and other legal information. Objections can be filed, and the burden of proof of non-impairment rests with the applicant. The regulatory process and the costs associated with it vary across states, in part because the no-harm mandate is defined differently.

By assigning ownership to specified amounts or flows of a highly variable resource stock, appropriative water rights exacerbate third-party effects occasioned by trades initiated by senior rights holders. The potential for third-party impairment raises the likelihood of protests and litigation by junior rights holders over water transactions. This reaction naturally raises the transaction costs of water exchanges. If, instead, water rights were granted as shares of the annual total allowable withdrawal from a water basin, adjustable according to precipitation, then all appropriators would share in any adjustments in total diversions due to precipitation shortfalls. Under this setting junior parties would not be differentially impacted by drought or as dependent upon released flows. Hence, the potential for third-party harm from trades would be reduced, especially if trades are limited to consumptive use. This setting requires significant additional information for measurement, bounding, and enforcing water rights.

Until the latter part of the twentieth century, third-party impairment generally was not an issue because most traded water stayed within the local agricultural community where demand was concentrated. In the face of contemporary pressures to reallocate water to other uses, however, protests of harm can be significant barriers to trade. The no-harm standard can be so vague, and the range of legal or regulatory standing so broad for parties to challenge proposed exchanges, that they can become mired in costly disputes and delay. This situation tends to keep water locked in current uses even though there are higher marginal values elsewhere (Hanak 2003). Restrictions on the transferability of water rights are an important limit on the rights holder. The potential to realize capital gains of moving assets to parties who can maximize their value provides incentives for prudent management and conservation investment.

16.4.2 The Problem of Water Rights Definition and Trading with Uncertain Flows

Burness and Quirk (1979) provide a useful framework for examining the issues of uncertain flows and the effect of appropriative rights. Let the volume of water available in a river be X, with $X \sim RV$ with *pdf* $f(x)$. There are n users who use quantity $(a_1, a_2, \ldots, a_n)$ and have a capacity of diversion $(\bar{a}_1, \bar{a}_2, \ldots, \bar{a}_n)$. Quantity used is the same as diversion capacity when sufficient water is available because: (1) no user will build a diversion facility larger than it has a right to; and (2) beneficial-use requirements require full application of all water. The rights are ordered so that firm 1 has priority over firm 2, and so on.

Diverters earn profits $\Pi_i(a_i, \bar{a}_i)$, with $\Pi_i^2 < 0$ and $\Pi_i^1 > 0$; profits are increasing in amount of water, but decreasing in amount of diversion capacity. The amount of water available to user i (i can only claim a maximum quantity of $\bar{a}_i$) is $X - A_{i-1}$, where A_i is the aggregate amount of claims to water based on seniority:

$$A_i = \sum_{j=1}^{i} a_i \tag{16.1}$$

Using this formulation the expected profit of diversion is as follows:

$$E\Pi = F(A_{i-1}) \cdot \Pi(0, \bar{a}_i) + \int_{A_{i-1}}^{A_i} \Pi(X - A_{i-1}, \bar{a}_i) \cdot f(x) \cdot dx \\ + [1 - F(A_i)] \cdot \Pi(\bar{a}_i, \bar{a}_i) \tag{16.2}$$

This framework allows an easy conceptualization of how uncertainty in water flows, combined with appropriative rights, impact a user's profit function. There are three terms, each weighted by their probability of occurring. The first is the loss when there is no water delivery; the second is the expected value with only partial water delivery; and the third is the profit with full water delivery. For identical firms, equal sharing is the efficient solution and prior appropriation is inefficient. Efficiency can be promoted under the appropriative doctrine with competitive markets in water rights.

Without trades, senior appropriators build more capacity and have larger water right allocations than juniors, even if the appropriators are identical except in seniority of rights (Burness and Quirk 1980). The cause of this is the unequal sharing of the risk of stream flow fluctuations, water deliveries, and priority of diversion. For economic efficiency, however, the value of production is the determinant of diversion and water consumption. Thus, we expect that efficiency in appropriative rights will only emerge when right holders can trade freely to align their productive activity with the risk profile of the water right. If all rights had the same risk profile, as with proportional rights, efficient allocation would be met when the law of one price held in the market. With appropriative rights, however, prices of junior rights will be lower than those of senior rights, reflecting the differences in delivery risk.

16.4.3 The Problem of Return Flow

Where upstream water users return a portion of their diversion, known as return flow, it has economic value to downstream users. Accordingly, the consumptive use of water, not the total diversion, becomes an important factor in determining the efficiency of the water allocation. This is shown by Johnson et al. (1981). Let S_i be the water diverted by a user i, one of n users, and R_i the proportion of S_i that is returned to the river. S_1 is the diversion by the first user on the river, and subscripts are ordered so that S_2 is the second diversion, and so on. Consumptive use is $C_i = S_i \cdot (1 - R_i)$. If the marginal product of water for each user is a function of consumptive use, $f_i'(C_i)$, then the following condition holds so long as sufficient water is available for diversion at each point:

$$\frac{f_1'(C_1)}{1 - R_1} = \frac{f_2'(C_2)}{1 - R_2} = \cdots = \frac{f_n'(C_n)}{1 - R_n} \qquad (16.3)$$

Total value is maximized when the marginal product of consumptive use among users is equalized.

Because appropriative rights have been defined by diversion, regulation rather than consumptive-use property rights has emerged to reduce the impairment of return flows. For instance, where appropriative rights are defined as S_i and a junior appropriator with a lower R_i purchases rights from a senior appropriator, the rights of other users may be impacted if consumption and return flow change. In this case, allowing transfers up to the amount of consumptive use will help to avoid third-party losses. Because appropriative rights generally do not define consumptive use, however, there is potential inefficiency during drought when stream flows are low and high-valued uses are threatened (Howe et al. 1982). An instance where trading up to consumptive use has been adopted is the Central Valley Project Improvement Act (CVPIA §3405 [1] [I]), but the costs of acquiring and verifying return flow information may be large.

Consumptive use rights, instead of diversion-based rights, offer a way to induce more efficiency in water markets. They do not, however, completely eliminate third-party effects of market transactions due to change in the spatial patterns of consumptive use and return flow. Consider user $n-1$ who requires S_{n-1} water to fulfill the diversion right and currently is exactly receiving that amount, but not more. If user n, who has consumptive right C_n, transfers water to a user, k, above $n-1$, flow is reduced to user $n-1$, who now only has access to $S_{n-1} - C_n$. With either type of right, some third-party effects may not be accounted for in market transactions.

Third-party effects occur for example with trades that shift water among parties with different irrigation efficiencies or from agriculture to urban uses at various points along the stream. More efficient irrigation systems have a much higher consumptive use coefficient. US Geological Survey (USGS) data indicate that agricultural consumptive use coefficients range from 70 to 90 percent even within the wetter Great Lakes Region states, while urban use coefficients are much lower, ranging from 10 to 15 percent (Shaffer and Runkle 2007). Third-party impairment also may occur if users have different diversion timing, such as shifting from diverting small amounts year-round to major withdrawals during the summer months when stream flows already are low. Finally, trades that degrade downstream water quality also have the potential to cause third-party damage. When water is used consecutively for agriculture it picks up minerals from the soil and can become progressively saltier, damaging the ability of downstream users to irrigate or use the water for municipal supply. Wastewater from cities has the same potential to cause harm to downstream users. Water quality changes and reductions in stream flow below certain thresholds can cause damage to aquatic and riparian ecosystems. Because water quality may impact health, which along with environmental benefits might go unmeasured, the ability of markets to properly value these effects may be limited. Despite all of this, regulatory restrictions to prevent these third-party impacts may be too broad and politically motivated and thereby reduce water trades excessively and reduce the ability of markets to equalize prices (Buchanan and Tullock 1962; Volden and Wiseman 2007). (We return to these trade-offs in our discussion of Figure 16.6 below.)

16.4.4 The Problem of Environmental Flows

In many settings, surface water has value as instream flow, whether for ecosystem support, pollution abatement, or provision of wildlife habitat and recreation. The challenge is that the return flow of a water right owned by an upstream user may also be claimed by a downstream user.

While instream users could purchase appropriative water rights from a diverter to supplement supplies, only the release of the consumptive portion will increase stream flows.

Griffin and Hsu (1993) provide a useful model of economic efficiency when instream flows have value. They argue that the use of water upstream has two effects. First, any consumptive use of water decreases water available downstream to diverters and instream users. Second, any non-consumptive diversion decreases the volume available between where it is diverted and where it returns to the system. Instream values may exist between any two points and are a function of the flow. Reduction of consumptive use of water by an upstream diverter increases instream flows and benefits all instream users. It also benefits diverters downstream who now bear less risk of not having sufficient water. This tells us to expect that upstream parties use less water in a socially optimal scenario than if they only considered private costs and benefits (Griffin and Hsu 1993). The presence of trade and instream flow rights allows upstream users to capture some of these social benefits and thus motivates them to move water to the socially optimal use.

Defining property rights to include the social benefits of increased downstream water use has higher transaction costs of measurement and enforcement. Such a definition, however, allows water prices to equalize along the river. The alternative of regulation to protect downstream users, without price signals as information about relative values, is potentially inefficient. Most western states have enacted instream flow rights legislation, and in states such as Oregon instream trading is active (www.thefreshwatertrust.org).

16.5 WATER SUPPLY ORGANIZATIONS: IRRIGATION DISTRICTS AND IMPLICATIONS FOR THE LAW OF ONE PRICE

Water supply networks require initial fixed investments in dams, reservoirs, canals, and feeder ditches to capture, store, and deliver water. Irrigated farms also require upfront investments in local ditches and water-intensive annual and perennial crops. This setting creates contracting hazards for investors in water supply organizations and for farmers. Both parties are dependent upon one another, but non-deployable capital, bilateral monopoly, hold-up, free-riding, and timing problems can undermine either endeavor (Bretsen and Hill 2006, pp. 288–292). The fixed costs of an irrigation network mean that there is likely to be only one water supply organization in any location, and it relies upon farmer demand in its delivery area. There is potential for either party to engage in opportunism to extract the associated quasi rents (Klein et al. 1978). The supply organization as monopolist can threaten to deny water during key growing periods to gain higher rates, and farmers can organize for lower prices by withholding demand. Long-term price and delivery contracts between water supply organizations and farmers also are complicated by the unpredictability of precipitation and stream flow. Right-of-way hold-up is possible because canals and ditches cross multiple land parcels in building an irrigation network of sufficient size. Free-riding is a threat as farmers located at the head of a ditch are less motivated to provide maintenance to ensure water flow to up-ditch farmers. Finally, in terms of timing and sequence of investment, agriculture is not feasible without upfront irrigation capital, but such investment requires agricultural demand to generate favorable rates of return for attracting funds. Hence, coordination of investment is a challenge for both parties (Libecap 2011).

In relatively straightforward cases, unincorporated, non-profit mutual irrigation associations are formed by small groups of farmers, who jointly agree to construct and maintain a water delivery infrastructure. Depending on the case, farmers may retain their individual water rights and priorities, with their ditch shares based on them; or all members may have the same priority, with shares allocated based on participation in the ditch association. This case-by-case difference introduces variation in water rights. Because of their low cost for simple networks, unincorporated mutual irrigation associations are popular, covering 46 percent of irrigated acreage in the West in 1910 and 56 percent in 1978 (Bretsen and Hill 2006, pp. 293–294).

Larger projects, however, require more complex arrangements, such as incorporated mutual irrigation companies or commercial irrigation companies. Mutuals are non-profits organized by farmers as shareholders. As above, water rights vary. Either the company holds the water rights and supplies water according to shares held by farmers, or the farmers retain their rights and receive the water as specified by their right. Because mutuals are initiated and managed by relatively homogeneous groups of farmers, they reduce the coordination cost of water delivery. They supplied 30 percent of irrigated acreage in 1910, declining to 16 percent by 1978 (Bretsen and Hill 2006, pp. 293–294). For-profit, commercial irrigation companies are among the earliest irrigation institutions but they have never been that prominent. Commercial irrigation companies declined from providing 11 percent of irrigated acreage in 1910 to 0.5 percent by 1978 (Bretsen and Hill 2006, pp. 293–294).

The most important water supply organization to emerge, and the one posing the greatest implications for contemporary water markets, is the irrigation district (Leshy 1982). These covered 4 percent of irrigated acreage in 1910 and nearly 25 percent by 1978 (Bretsen and Hill 2006, pp. 293, 312–327), but these figures understate the amounts of water to which many irrigation districts have claims today. For example, one of the country's largest irrigation districts, the Imperial Irrigation District of Southern California, annually diverts 2.8 million AF of Colorado River water, nearly two-thirds of California's legal share of the river.[4] The district includes 495 000 acres of cropland as well as urban areas.

Irrigation districts have direct access to Bureau of Reclamation (BOR) water, following congressional legislation in 1922 and 1926 authorizing, and then requiring, the agency to contract only with irrigation districts in the provision of federal agricultural water. The BOR is the largest wholesaler of water in the US and it provides irrigation water for 140 000 farms covering 10 million acres in 17 western states. It has over 600 dams and reservoirs to capture and divert water, historically mostly for irrigation.[5] The bureau provides water to the irrigation districts through long-term service contracts. The bureau can hold an appropriative right to the water within a reclamation project and the water is distributed anywhere within the project; the water right can be held by the irrigation district served; or the water rights can be held by district members. Table 16.3 lists the variety of water supply organizations across the western states.

In California (and many other western states), most surface water rights today are held by irrigation districts, special water districts, and some municipalities (Hanak and Stryjewski 2012). These owners face

Table 16.3 Water supply management organizations in the Western US

State	Irrigation, water, and water conservancy districts and mutual ditch companies	Other public water management organizations	Total
AZ	46	85	131
CA	169	123	292
CO	34	109	143
ID	79	53	132
MT	55	8	63
NM	10	22	32
NV	8	21	29
OR	49	25	74
TX	29	17	46
UT	9	75	84
WA	41	22	63
WY	27	11	38

non-economic political incentives that are different from private owners and firms because of differences in governance and voting rules regarding water transfers. In many states, only landowners within an irrigation district comprise the governing board and vote on water exchanges. In California, Idaho, and Kansas all registered voters within the district may be eligible. A wide franchise grants decision-making over water rights, allocation, and management to a diverse group of non-farm community members, tenant farmers, and landowners. Their interests in water exchange are unlikely to coincide, and this condition raises the transaction costs of trade (Thompson 1993, pp. 678, 728, 740; Rosen and Sexton 1993, pp. 40–41, 49–52; Bretsen and Hill 2006, pp. 320–323; 2009, p. 737).

In these public irrigation districts water is common or community-wide property, where it is uncertain who has the authority to change use or trade water. Public irrigation districts typically control the water their members use and require board approval for members to trade water out of the district. Other members who do not receive a benefit from the trade, but see a decreased volume of water to cover fixed costs, may oppose such transfers. If they are also rights holders, however, they may have the incentive to allow transfers to protect the ability to sell their water rights in the future. The non-irrigating voters receive no benefit from water sales and the reduction of water in their district may lead to pecuniary losses through reduced demand for agricultural labor or farm machinery following a switch to less water-intensive crops or fallowing land.

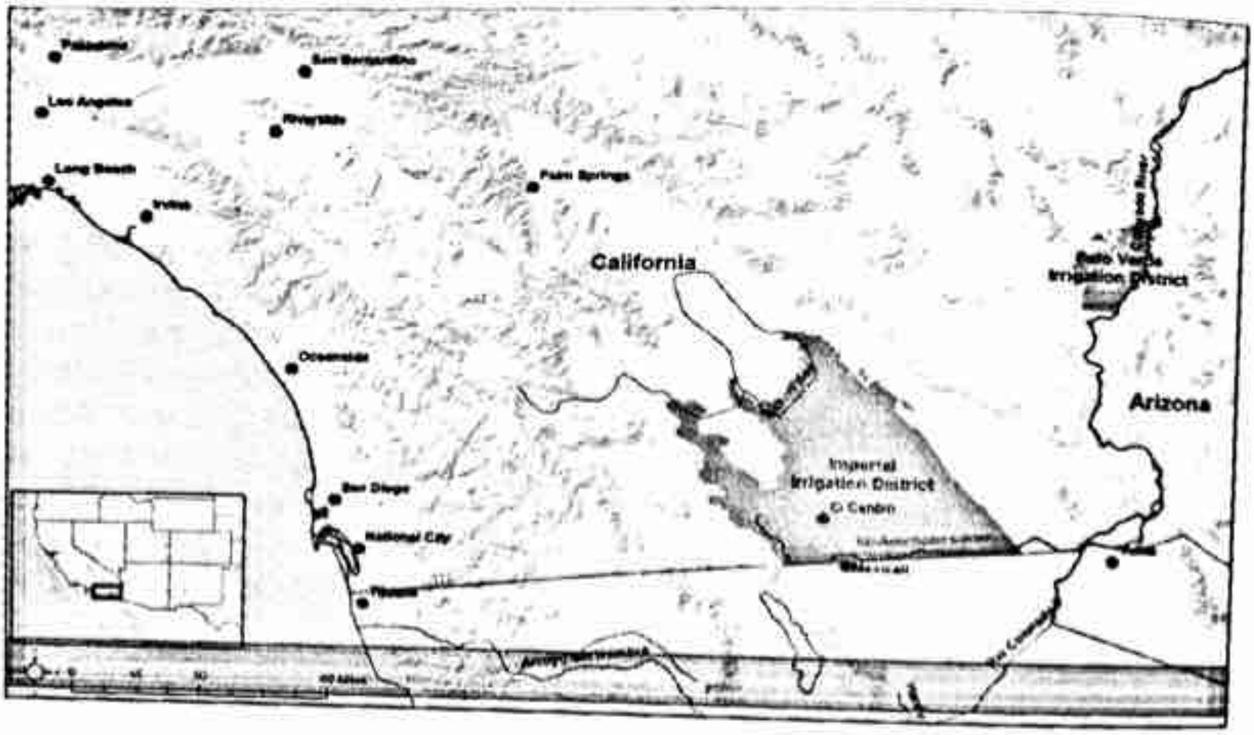
Historically when water was less scarce and agriculture the dominant use, a diffuse water rights relationship between the district and its members was of little consequence. Transfers were among members and arranged informally to meet seasonal shortfalls. Today, as marginal water values outside of agriculture have become much higher than those within it, long-term transfers increasingly are to out-of-district users. When water rights are vague and diffusely held, the disbursement of benefits and costs of exchange is unclear. Under these circumstances, farmers lack incentives to leave marginal land idle, to invest in on-farm water conservation, or to participate in Pareto-improving, long-term water trades. The potential revenues to water sellers are especially large for districts near urban areas or with means of conveyance to them. For example, Glennon (2002, p. 207) reports that in 2001 land developers near the Grand Canyon National Park offered \$20 000/AF for Colorado River water used by farmers downstream in the Imperial Irrigation District (IID) who paid \$13.50/AF.

Besides public irrigation district rules where water rights effectively are broadly held, California counties are able to restrict the extraction and export of groundwater out of county through county-of-origin restrictions.

As of 2002, 22 of 58 counties had done so (Hanak and Dyckman 2003). These county ordinances similarly can limit surface water transactions if they appear to diminish groundwater resources, either through lowered recharge or through greater farmer reliance upon pumping. Although there are legitimate groundwater issues at stake, research by Hanak (2003, p. viii) suggests that the overriding aim of the ordinances is to keep water within rural counties and limit reallocation to urban or environmental uses.

16.5.1 Imperial and Palo Verde Irrigation Districts and the Law of One Price

The implications of irrigation district structure for water trading are illustrated by the comparative experiences of two California districts, the public Imperial Irrigation District and the nearby private Palo Verde Irrigation District (PVID) (Figure 16.4), where only landowners determine board membership and policies (Rosen and Sexton 1993, pp. 43–51; Haddad 2000, pp. 74–92; Glennon 2009, pp. 258–271; Bretsen and Hill



Sources: Created by the authors using publicly available data from an ESRI base map with data from Tele Atlas North America, Automotive Navigation Data, and US Geological Survey. Added data includes the All-American Canal line feature from the US Census Bureau, IID shapefile from the US Bureau of Reclamation, PVID shapefile from the County of Riverside, and river line features from Natural Resources Canada.

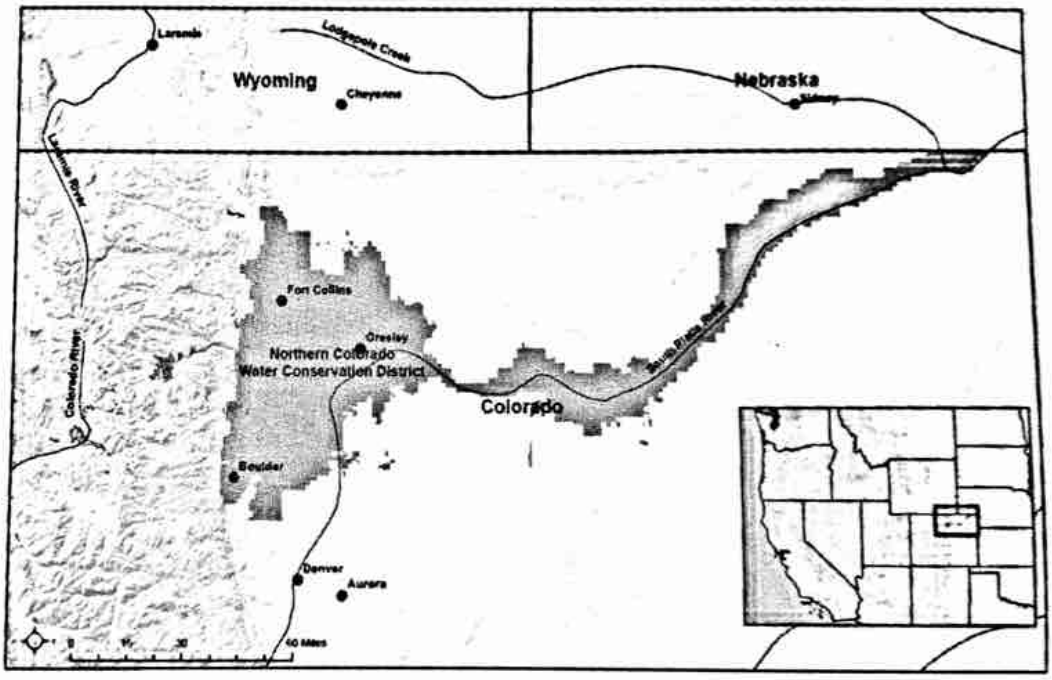
Figure 16.4 Imperial and Palo Verde irrigation districts

2009, pp. 756–760). Negotiations between the IID governing board and officials of the Metropolitan Water District of Southern California (MWD) and the San Diego County Water Authority (SDCWA) for long-term water leases occurred between 1984 and 2003. Agreements were reached, but collapsed in the face of opposition from a variety of parties. Only after the intervention of the US Department of the Interior that administers Colorado River water and that supported a reallocation of IID water was an agreement finally concluded in 2003 to transfer over 30 million AF to urban users over 75 years. Because fallowing was so contentious, water for transfer had to be secured through ditch lining to reduce seepage even though fallowing was likely more cost-effective (Rosen and Sexton 1993, p. 51).

Negotiations between the PVID governing board and the MWD were much smoother, faster, and less contentious. The PVID is also a large district, irrigating 131 298 acres with 450 000 AF of water diverted annually from the Colorado River.[6] One set of negotiations over water began in 1986 and were successfully concluded in 1992. Another started in 2002 with agreement in 2004. Both involved dry-year options, whereby farmers were to fallow designated land when requested by the MWD and to release the water to the agency for urban delivery (Haddad 2000, pp. 95–115). The MWD set up a fund to address third-party effects in the community. These, however, did not play a significant role in the negotiations (Glennon 2009, pp. 264–271).

16.5.2 The Colorado–Big Thompson Bureau of Reclamation Project, Water Rights, and the Law of One Price

The Colorado–Big Thompson (CBT) Project (Figure 16.5) is a trans-basin diversion, bringing supplemental water from the Colorado River Basin to the South Platte River Basin in north-eastern Colorado, supplying about 30 percent of the water in that region (Howe and Goemans 2003, p. 1056). The project was constructed by the Bureau of Reclamation between 1938 and 1957 and is managed by the Northern Colorado Conservancy District (Tyler 1992). Water is pumped across the continental divide through tunnels and stored in 12 reservoirs and moved through a series of canals to agricultural, urban, and industrial users. The water supplies 1.6 million acres of land in portions of eight Colorado counties. The CBT annually delivers an average of 270 000 AF to agricultural, municipal, and industrial uses (Howe and Goemans 2003).[7] The CBT is unusual among BOR projects in that it supplies new water stored in reservoirs to existing users. As imported water from another basin, all return flows are owned by the Northern Colorado Conservancy District and cannot be claimed



Sources: Created by the authors using publicly-available data from an ESRI base map with data from Tele Atlas North America, Automotive Navigation Data, and US Geological Survey. Added data includes administrative boundaries from Northern Colorado Water Conservation District, lake shapefiles from Lake County Colorado, and river line features from Natural Resources Canada.

Figure 16.5 The Colorado–Big Thompson Project (Northern Colorado Conservancy District) separately by other parties. This provision reduces conflict over potential third-party impairment in water trades and lowers the transaction costs of trade.[8] Further the distribution of water rights was in tradable shares of the annual amount of water available to the district.[9] These units can be exchanged among all users, agricultural, urban, and industrial alike, within the district. Because shares are homogeneous, transfers across users, especially across sectors, occur with minimal fees and paperwork (Thompson 1993, p. 719; Carey and Sunding 2001, p. 305; Howe and Goemans 2003, pp. 1058–1059). Additionally, the district administers proposed trades rather than the larger and more politically and institutionally complex BOR.

For these reasons, the CBT has by far the most active water market in the West in terms of numbers of trades. Sales prices for all uses are comparable, obeying the law of one price as expected when opportunity costs are incorporated, water quality and right priority are the same, and transaction costs are low.[10] Pricing patterns are indicated in Figure 16.2.

16.6 WELFARE LOSSES OF INCOMPLETE TRADE

16.6.1 Welfare and Externality

When property rights fail to define the amount and location of diversion and return flow, upstream water transfers potentially create a negative externality downstream, although the magnitude of the externality may be large or small. The buyer and seller do not consider the cost of the downstream damage, whether to another user or to the environment, because both the upstream and downstream parties use, but do not fully own, the water right. The magnitude of the deadweight loss from the externality is shown in Figure 16.6 that displays a hypothetical example of potential sales of water out-of-basin. Seller private reservation prices are represented by curve $S(P)$ and buyer reservation prices by curve $D(P)$. Water trading without accounting for downstream social costs, such as third-party and environmental damage, causes too much water to be traded. The market equilibrium, at quantity Q_H, is too high, resulting in trade surplus of area F but social losses of $E + F$, making the deadweight loss resulting from the externality area E.

While injury to third parties reflects an externality, we can see in the figure that harm may occur even at the socially optimal level of trade, Q_O. Here, market transactions may injure downstream users, as we discussed earlier, represented by area $B + D$, but the loss is efficient, in the sense that

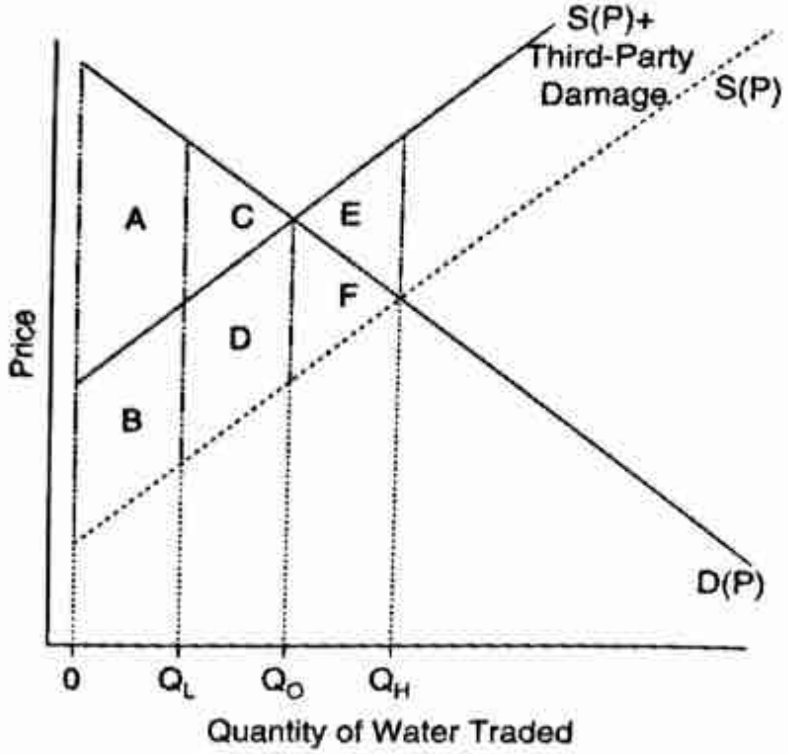


Figure 16.6 *Externalities and optimal harm of water transfers*

the private surplus of trade is area $A + B + C + D$, resulting in overall social gains of $A + C$. Reducing the amount of water transferred below Q_O, for instance to Q_L, perhaps through the regulatory process, decreases gains from trade by more than it reduces the losses to third parties. In this case, the social gain from trade is area A, while the lost social gain relative to trade at Q_O is area C.

Where it is prohibitively expensive to solve the externality problem, it is Pareto-irrelevant (Buchanan and Stubblebine 1962). In this case, Q_H may be the second-best solution that maximizes welfare (Dahlman 1979, p. 149). However, even if water trades increase societal welfare, downstream users and others who do not directly benefit from the transfer have the incentive to prevent them. Regulations requiring no injury to third parties may result in no water exchange, and thus the loss of social gains from trade of area $A + C$, because any trade causes some harm. We do not necessarily expect regulators to maximize social welfare, because their choice of policy may result from other factors (Schroeder 2010), including an incentive to minimize the amount of political criticism (Leaver 2009). Bargaining to compensate third parties can allow for trade beyond Q_O. When the costs of bargaining are high, as they can be when there are many downstream users (assembly problem) or one (bilateral monopoly problem), less water trade will occur.

16.6.2 Allocative Welfare Loss

An important cost to assess in determining the welfare loss of restrictions on water trading is allocative cost. For many large water projects, such as the construction of a dam, new water is made available through the storage of runoff that would otherwise not be used for irrigation. In the case of the BOR, this water is then distributed to farmers at low cost. While there is evidence that there are significant subsidies in the cost these users pay for the water (Wahl 1989), subsidies by themselves will not lead to inefficient pricing in water markets – just a wealth transfer from the government to farmers, if they can then sell the water at the market price. However, even if subsidies do not exist, there are potential losses associated with a lack of water markets where water is allocated by a method other than price. These are known as allocative costs.

The rules for water allocation from BOR projects were specifically designed to direct water to the agricultural sector and had specific acreage limits. This type of allocation could result in misallocation and welfare losses, although this will only be the case where the shadow value of water in agriculture is lower than in alternative uses (Kanazawa 1993). Accordingly, it is not clear a priori that BOR allocations historically were inefficient. As water values outside of agriculture have become higher there is the potential for welfare losses due to the initial allocations if transaction costs are high (Coase 1960, p. 15). Water trading can mitigate these losses, but regulatory restrictions as described in Figure 16.6 can lock in these allocation effects (Landry 2001).

16.6.3 Welfare Benefits of Additional Trading

It is not clear without analysis of empirical evidence whether regulation to restrict trade is social-welfare-increasing. Regulatory-induced transaction costs could act as a Pigouvian tax, moving trading from Q_H to Q_O in Figure 16.6 (Colby 1990). However, the price differentials between agriculture-only transfers and transfers from agriculture to municipal users in the western US are often so large that net welfare benefits from increased exchange seem likely. Less than 3 percent of water withdrawals are traded in the West's largely rural states of Idaho, Montana, and Wyoming. The more urbanized states of Arizona, California, Colorado, Nevada, and Texas annually trade between 5 and 15 percent of total freshwater diversions. Data from *Water Strategist* indicate that nearly all the water purchased by urban buyers was within these five states, but price differences by sector remain large.

Grafton et al. (2012) estimate the potential gains of a 5 percent transfer

Table 16.4 Hypothetical benefits of water transfers at current prices

State	Total irrigation withdrawals per year (AF)	22-year median ag-to-ag/ ag-to-urban price difference in AF (2008 $)	Yearly gain of a 5% transfer of irrigation water to urban users at 22-year median transfer prices (2008 $)	Current value of urban market per year (2008 $)
AZ	2 540 000	$11.58	$2 236 598	$25 252 731
CA	15 700 002	$26.53	$31 680 746	$77 992 925
CO	10 000 001	$155.61	$118 380 995	$33 660 033
NV	1 550 000	$115.53	$13 622 001	$19 092 630
TX	8 740 001	$13.25	$8 805 878	$34 065 103

Source: Grafton et al. (2012).

of irrigation water to municipal water users at current average transfer prices in five western US states. The results of this exercise are shown in Table 16.4. The second column provides a measure of total irrigation withdrawals per year from Keny et al. (2009) and the fifth column provides current per-year market transfers in each state from *Water Strategist* data. The third column shows the average 22-year price difference between agriculture-to-urban and within-agriculture transfers in constant 2008 dollars. The long time window is used to compensate for a lack of trading data at the state level for shorter periods. The fourth column provides estimates of the hypothetical value of a 5 percent transfer of irrigation withdrawals to urban users. The resulting estimates indicate the high value of water if it could be transferred with zero transaction costs and without changing relative price differences. The potential gains are in excess of US$50 million/year.[11] There is a limit to the amount of agricultural water that urban areas will buy, however, because agricultural water prices will rise and urban prices will decline as the law of one price begins to hold. However, high urban growth in the southwest US indicates strong continuing demand.

16.7 ISSUES IN THE PROGRESSION OF RIGHTS AS VALUES RISE

We have described the potential for third-party impairment in water trading under the appropriative rights system. A system with rights based on proportional shares, where allocations are allotted by historical diversion or consumption, is a potential alternative. Share allocation among existing rights holders using either criteria is suggestive of the information required for implementation and of the bargaining problems likely to be encountered. Distribution of shares based on historical consumptive use, which would reduce third-party effects of water exchanges along a water system, requires far more information and is apt to be far more contentious in reaching agreement on a share rights allocation. Accordingly, it may not Pareto-dominate a distribution based on historical diversions, but even that approach is likely to be controversial if there is limited information on past diversions or if diversions have exceeded legal allocations.

In either case, an annual cap on water diversions or consumption by all parties within a water basin is required, with the cap variable according to expected precipitation (water supply) and new demands, such as stream flow targets for environmental habitat and recreation. The cap itself is likely to be controversial, as it is in many fisheries where fishers and regulators disagree on fish stock conditions and restrictions on total harvest (Acheson 2003). Accordingly, setting the cap and distributing shares to it are unlikely to be straightforward, as described below, even in the presence of potential aggregate efficiency gains.

In addition to reducing third-party effects via return flow changes if shares rather than appropriative rights are traded, shares also place rights holders in the same risk profile regarding water availability. In times of shortage, for instance when the flow of the river is at 80 percent of normal, users receive 80 percent of their share, which is not the case under the appropriative system where senior rights holders may receive their full water allocation while lower-priority claimants receive none. Share allocation is common within many irrigation districts, where cutbacks in water to the district result in cutbacks to all users. Shares align all users' incentives for information gathering on how much water is available in the system, and all bear proportionate costs as water is set aside for the maintenance of instream flows. Further, the transaction costs of exchange are reduced because water is traded in uniform units (shares) and the costs of determining seniority and certainty of water availability within the right, as is the case with appropriative rights, are avoided.

The advantages of shares in other contexts are indicated by the shift from fixed quantities in New Zealand's individual transferable quota system in fisheries, first implemented in 1986, to shares when overall allocations were found to lead to stock depletion (Connor and Shallard 2010). Further, as we have noted, the Colorado–Big Thompson supports the most active water market in the US West (Howe et al. 1986). All return flows are held by the Northern Colorado Conservancy District that governs the CBT so that the distinction between diversion and consumption is less critical in rights definition and trade.

Despite these advantages a shift from prior appropriation to shares is unlikely to be widespread in the US West unless water becomes much more valuable; the costs of third-party impairment rise dramatically; and trade remains seriously impeded. To illustrate the costs of some historical rights adjustments, a negotiated settlement in 1939 between a riparian rights holder on the San Joaquin River, Miller and Lux Incorporated, and the US Bureau of Reclamation, required payment of \$41 billion (2013 dollars) to facilitate construction of the Friant Dam (US Bureau of Reclamation 1939). Riparian rights are similar to shares, but with the share allocation based on land frontage along a waterway. The high price of the exchange with a single rights holder, essentially a buyout to implement an appropriative right system, is indicative of the scale of the cost of changing a property right system once established.

Existing rights holders must perceive that they are made better off, or at least no worse off, from the adjustment. Agreement among all parties on the new rights allocation and associated compensation may not be forthcoming due to disagreements over expected values. Uncertainty is particularly likely for those parties who do well under the current rights allocation: high-priority rights holders and, in other contexts, skilled fishers (highliners) or owners of very productive oil leases on a hydrocarbon reservoir. Empirically, highliners oppose imposition of share quotas (Johnson and Libecap 1982; Deacon et al. 2013) and owners of small, very valuable oil leases resist unitized management and share distributions (Wiggins and Libecap 1985; Libecap and Smith 2002). Due to asymmetric information and uncertainty the parties cannot agree on an allocation of rents that makes all better off relative to the status quo.

To see the challenges involved in reaching agreement on a redefinition of property rights, consider a simple bargaining problem where water rights are currently held by a low-value user who is negotiating with a high-value user. Normalize the range of value of each party as between 0 and 1. The high-value user values the water at h, the low-value user at l:

$$h, l \in [0, 1]$$

If there are no costs to bargaining, there can be an agreement as long as $h - l > 0$. This is the Nash (1953) demand game. It can be shown that any agreement price t can be a Nash equilibrium where:

$$t \in [l, h]$$

Determining the precise value of t that will emerge, however, is more complicated. Intuition and math tells us equilibrium should emerge and trade should take place, yet in varied settings including negotiations over water rights, oil field unitization, and fisheries tradable quota systems, agreements often do not emerge. We argue that this should partially be attributed to uncertainty over the true values of l and h held by the relevant parties. Applying a distribution to l and h such that they are uniform random variables distributed between zero and one changes the potential bargaining outcome dramatically. Each user knows their own type and the distribution of the other's type. The users make bids based on linear strategies to maximize their expected value, leading to agreement only if $h - l \geq 1/4$ (Fudenberg and Tirole 1991, p. 222). This simple exercise suggests that our intuition from a deterministic setting does not translate into a situation where uncertainty over resource values and rights exists. Accordingly, opposition from senior diverters to any adjustment in water rights is likely. Only when the costs of the current arrangement become so high that the status quo is no longer tenable will the rights system be changed voluntarily.

16.8 CONCLUSION

The failure of western water markets to obey the law of one price is fundamentally a result of the institutional framework through which water is allocated and managed. Characteristics of water use such as the amount of diversion, percentage of consumption, and timing and location of diversion are important elements of the value of water. This chapter has examined why measurement, bounding, and enforcement of surface water rights are costly. Where this is the case, incomplete rights exist, leading to third-party damage and public-good losses from diminished instream flows when trades take place. While regulation offers a potential solution to these problems when water value is low, as water values rise these restrictions can lead to the large price differences seen among different types of buyers. Regulators and the opponents of exchange are not the residual claimants to the increased rents from exchange. Because water management institutions evolve over time, path-dependencies are critical in explaining irregularities in water market pricing. These types of institutional factors offer economists an opportunity to study the interaction of markets, property rights, and regulation. The key challenge, however, is the limited and proprietary nature of much of the data on transfers and prices.

NOTES

1. One acre-foot is about 326000 gallons of water.
2. This dataset is available at http://www.bren.ucsb.edu/news/water_transfers.htm.
3. These calculations are based on the dataset as described in Brewer et al. (2008a).
4. Under the 1922 Colorado River Compact (http://www.usbr.gov/lc/region/g1000/lawofrvr.html) and the US Supreme Court decision in *Arizona v. California 373 U.S. 546*, California is granted 4.4 million AF annually. It regularly diverts 5.1 to 5.3 million AF, however (Haddad 2000, pp. 70–71; Glennon 2009, p. 258).
5. US Bureau of Reclamation website: http://www.usbr.gov/main/about/.
6. Palo Verde Irrigation District website: www.pvid.org/.
7. Northern Colorado Water Conservancy District website: http://www.ncwcd.org/.
8. The notion is that the natural flow claimed by existing water rights holders is not negatively affected by the import or trade of new water. According to Clay Landry of WestWater Research the argument could be made that stored water within a basin has similar benefits as imported water and should not be held to traditional third-party injury tests. In fact, the BOR currently treats its other Colorado River storage contracts according to this view by allowing the full quantity of the contract to be transferred and not limiting it to historical consumptive use to address potential injury issues.
9. As discussed by Howe et al. (1986, p. 443), each share or unit is 1/310000 of the water available to the Northern Colorado Conservancy District.
10. For example, sample agriculture-to-urban and agriculture-to-agriculture sales were priced at $9350 and $9300 per unit, respectively, as reported in the October 2008 *Water Strategist*, p. 7. The CBT also has the advantage of using reservoir water, imported from elsewhere, providing a less complex case than when flowing streams are the water sources (Howitt and Hansen 2005, p. 60).
11. This estimate excludes Colorado where conveyance costs are high for moving water, often across the continental divide, to where the urban population is located.

REFERENCES

Acheson, J.M. (2003). *Capturing the Commons: Devising Institutions to Manage the Maine Lobster Industry*. Hanover: University Press of New England.

Allen, D.W. (2000). Transaction costs. In Boudewijn Bouckaert and Gerrit De Geest (eds), *The Encyclopedia of Law and Economics*, Vol. 1. Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 893–926.

Anderson, T. and P. Hill (1975). The evolution of property rights: a study of the American West. *Journal of Law and Economics*, 18, 163–179.

Baffes, J. (1991). Some further evidence on the law of one price: the law of one price still holds. *American Journal of Agricultural Economics*, 73(4), 1264–1273.

Barzel, Y. (1982). Measurement costs and the organization of markets. *Journal of Law and Economics*, 25(1), 27–48.

Barzel, Y. (1997) *Economic Analysis of Property Rights*, 2nd edn. New York: Cambridge University Press.

Bretsen, S. and P. Hill (2006). Irrigation institutions in the American West. *UCLA Journal of Environmental Law and Policy*, 25, 283.

Bretsen, S. and P. Hill (2009). Water markets as a tragedy of the anticommons. *William and Mary Environmental Law Review*, 33(3), 723–783.

Brewer, J., M.A. Fleishman, R. Glennon, A. Ker and G. Libecap (2008b). Law and the new institutional change in California, 1987–2005. *Washington University Journal of Law and Policy*, 26, 183–214.

Brewer, J., R. Glennon, A. Ker and G. Libecap (2008a). Water markets in the west: prices, trading, and contractual forms. *Economic Inquiry*, 46(2), 91–112.

Brewer, J. and G.D. Libecap (2008). Property rights and the public trust doctrine in environmental protection and natural resource conservation. *Australian Journal of Agricultural and Resource Economics*, 53(1), 1–17.

Brookshire, D.S., B. Colby, M. Ewers and P.T. Ganderton (2004). Market prices for water in the semiarid west of the United States. *Water Resources Research*, 40, W09S04.

Brown, T.C. (2006). Trends in water market activity and price in the western United States. *Water Resources Research*, 42, W09402.

Buchanan, J.M. and W.C. Stubblebine (1962). Externality. *Economica*, N.S. 29(116), 371–384.

Buchanan, J.M. and G. Tullock (1962). *The Calculus of Consent*. Ann Arbor, MI: University of Michigan Press.

Burness, H. and J. Quirk (1979). Appropriative water rights and the efficient allocation of resources. *American Economic Review*, 69(1), 25–37.

Burness, H. and J. Quirk (1980). Water law, water transfers, and economic efficiency: the Colorado River. *Journal of Law and Economics*, 23, 111.

Carey, J.M. and D.L. Sunding (2001). Emerging markets in water: a comparative institutional analysis of the Central Valley and Colorado–Big Thompson projects. *Natural Resources Journal*, 4, 283–328.

Coase, R.H. (1960). The problem of social cost. *Journal of Law and Economics*, 3, 1–44.

Colby, B.G. (1990). Transactions costs and efficiency in western water allocation. *American Journal of Agricultural Economics*, 72(5), 1184–1192.

Connor, R. and B. Shallard (2010). Evolving governance in New Zealand fisheries. In R. Quentin Grafton, Ray Hilborn, Dale Squires, Maree Tait and Meryl Williams (eds), *Handbook of Marine Fisheries Conservation and Management*. New York: Oxford University Press, pp. 347–359.

Dahlman, C.J. (1979). The problem of externality. *Journal of Law and Economics*, 22(1), 141–162.

Deacon, R.T., D.P. Parker and C. Costello (2013). Reforming fisheries: lessons from a self-selected cooperative. *Journal of Law and Economics*, 56(1): 83–125.

Demsetz, H. (1967). Toward a theory of property rights. *American Economic Review*, 57(2), 347–359.

Fudenberg, D. and J. Tirole (1991). *Game Theory*. Cambridge, MA: MIT Press.

Glennon, R.J. (2002). *Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters*. Washington, DC: Island Press.

Glennon, R.J. (2009). *Unquenchable: America's Water Crisis and What to do About It*. Washington, DC: Island Press.

Grafton, R.Q., G.D. Libecap, E.C. Edwards, R.J. O'Brien and C. Landry (2012). Comparative assessment of water markets: insights from the Murray–Darling Basin of Australia and the western USA. *Water Policy*, 14(2), 175.

Grainger, C.A. and C. Costello (2011). The value of secure property rights: evidence from global fisheries. No. w17019, National Bureau of Economic Research.

Gray, B.E. (1994). The modern era in California water law. *Hastings Law Journal*, 45(January), 249–308.

Griffin, R.C. and S.-H. Hsu (1993). The potential for water market efficiency when instream flows have value. *American Journal of Agricultural Economics*, 75(2), 292–303.

Haddad, B.M. (2000). *Rivers of Gold: Designing Markets to Allocate Water in California*. Washington, DC: Island Press.

Hanak, Ellen (2003). *Who Should be Allowed to Sell Water in California? Third-Party Issues and the Water Market*. San Francisco, CA: Public Policy Institute of California.

Hanak, E. and C. Dyckman (2003). Counties wresting control: local responses to California's statewide water market. *University of Denver Water Law Review*, 6, 490–668.

Hanak, E. and E. Stryjewski (2012). California's water market, by the numbers: update 2012. San Francisco: Public Policy Institute of California

Howe, C., P. Alexander and R. Moses (1982). Performance of appropriative water rights systems in the western United States during drought. *Natural Resources Journal*, 22, 379–89.

Howe, C.W. and C. Goemans (2003). Water transfers and their impacts: lessons from three Colorado water markets. *Journal of the American Water Resources Association*, 39, 1055–1065.

Howe, C.W., D.R. Schurmeier and W.D. Shaw (1986). Innovative approaches to water allocation: the potential for water markets. *Water Resources Research*, 22(4), 439–445.

Howitt, R.E. and K. Hansen (2005). The evolving western water markets. *Choices*, 20(1), 1–12.

Johnson, R., M. Gisser and M. Werner (1981). The definition of a surface water right and transferability. *Journal of Law and Economics*, 24(2), 273–288.

Johnson, R.N. and G.D. Libecap (1982). Contracting problems and regulation: the case of the fishery. *American Economic Review*, 72(5), 1005–1022.

Kanazawa, M. (1993). Pricing subsidies and economic efficiency: the US Bureau of Reclamation. *Journal of Law and Economics*, 36, 205–234.

Kanazawa, M. (1998). Efficiency in western water law: the development of the California Doctrine, 1850–1911. *Journal of Legal Studies*, 27(1), 159–184.

Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace and M.A. Maupin (2009). Estimated use of water in the United States in 2005. *US Geological Survey Circular*, 1344, 52.

Klein, B., R.G. Crawford and A.A. Alchian (1978). Vertical integration, appropriable rents, and the competitive contracting process. *Journal of Law and Economics*, 21(2), 297–326.

Landry, C.J. (2001). How water markets can end conflicts. Bozeman, MT: Political Economy Research Center, http://www.perc. org/pdf/guide water.pdf.

Leaver, C. (2009). Bureaucratic minimal squawk behavior: theory and evidence from regulatory agencies. *American Economic Review*, 99(3), 572–607.

Leshy, J.D. (1982). Irrigation districts in a changing West–an overview. *Arizona State Law Journal*, http://ssrn.com/abstract=1600445 or http://dx.doi.org/10.2139/ssrn.1600445.

Libecap, G. (1978). Economic variables and the development of the law: the case of Western mineral rights. *Journal of Economic History*, 37(2), 338–362.

Libecap, G.D. (1989). Distributional issues in contracting for property rights. *Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft*, 145, 6–24.

Libecap, G. (2007). The assignment of property rights on the western frontier: lessons for contemporary environmental and resource policy. *Journal of Economic History*, 67(2), 257–291.

Libecap, G.D. (2009). Chinatown revisited: Owens Valley and Los Angeles – bargaining costs and fairness perceptions of the first major Water Rights Exchange. *Journal of Law, Economics, and Organization*, 25(2), 311–338.

Libecap, G. (2011). Institutional path dependence in climate adaptation: Coman's 'Some unsettled problems of irrigation'. *American Economic Review*, 101(1), 64–80.

Libecap, G.D. and D. Lueck (2011). The demarcation of land and the role of coordinating property institutions. *Journal of Political Economy*, 119(3), 426–467.

Libecap, G. and J. Smith (2002). Economic evolution of petroleum property rights in the United States. *Journal of Legal Studies*, 31(2, Pt. 2), S589–S608.

Lueck, Dean (1995). The rule of first possession and the design of the law. *Journal of Law and Economics*, 38(2), 393–436.

McCann, L. and K.W. Easter (2004). A framework for estimating the transaction costs of alternative mechanisms for water exchange and allocation. *Water Resources Research*, 40(9), W09S09.

Nash, J. (1953). Two-person cooperative games. *Econometrica*, 128–140.

Rosen, M.D. and R.J. Sexton (1993). Irrigation districts and water markets: an application of cooperative decision-making theory. *Land Economics*, 69(1), 39–53.

Sax, J.L. (1990). The Constitution, property rights and the future of water law. *University of Colorado Law Review*, 61, 257–282.

Schroeder, C. (2010). Public choice and environmental policy: a review of the literature. In Dan Farber and Anne Joseph O'Connell (eds), *Handbook on Public Law and Public Choice*. Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 450–485.

Shaffer, K.H. and D.L. Runkle (2007). Consumptive water–use coefficients for the Great Lakes Basin and climatically similar areas. US Geological Survey Scientific Investigations Report 2007–5197.

Smith, H. (2000). Semicommon property rights and scattering in the open fields. *Journal of Legal Studies*, 29(1), 131–169.

Thompson, B.H. (1993). Institutional perspectives on water policy and markets. *California Law Review*, 81, 673–764.

Tyler, D. (1992). *The Last Water Hole in the West: The Colorado–Big Thompson Project and the Northern Colorado Water Conservancy District*. Niwot, CO: University Press of Colorado.

US Bureau of Reclamation (1939). Contracts for purchase of water rights and exchange of waters between Miller and Lux contracting companies and United States Bureau of Reclamation. http://cdm15911.contentdm.oclc.org/cdm/ref/collection/p15911coll9/id/3076.

Volden, C. and A.E. Wiseman (2007). Bargaining in legislatures over particularistic and collective goods. *American Political Science Review*, 101(1), 79–92.

Wahl, R. (1989). *Markets for Federal Water: Subsidies, Property Rights, and the Bureau of Reclamation*. Washington, DC: Resources for the Future.

Wiggins, S.N. and G.D. Libecap (1985). Oil field unitization: contractual failure in the presence of imperfect information. *American Economic Review*, 75(3), 368–385.

Williamson, Oliver (1975). *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: Free Press.

Young, R.A. (1986). Why are there so few transactions among water users? *American Journal of Agricultural Economics*, 68, 1143–1151.