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Property rights and western United States water markets*

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This paper addresses water scarcity issues in the American West and examines the allocation of water through the appropriative rights system and the extent markets are used to reallocate water from low- to high-valued uses. The unique physical properties of water make it difficult to bound and measure, which makes defining property rights difficult. Markets are also impeded by disputes over third-party effects due to the interdependencies of water users and complex institutional arrangements that dilute decision-making authority. Analysis of water trading in the western United States indicates that the rate of permanent transfers is increasing over time and urban users are paying higher prices relative to agricultural users.

Key words: property rights, water resources

1. Introduction

The economic and natural resource literatures have paid great attention to the problem of water scarcity (Kaiser and McFarland 1997) and for good reason; a combination of population growth, new water uses and concerns over future water availability are placing demands on water that are greater than available supplies. In the semiarid western United States, growth in agricultural production and population are increasingly calling for new water sources. Water allocation for environmental flows and recreational uses are also placing newer demand on water supplies. Over the past few decades, meeting these requirements in the western United States has shifted away from supply augmentation and toward conservation and water markets.

Historically, federally subsidised water projects were developed to augment water supplies by building dams, reservoirs and canals to capture, store and transmit water (Chong and Sunding 2006). Today, most high quality dam sites have been taken. Moreover, environmental objections to dams and reservoirs further reduce supply growth as a viable way to meet demand (Glennon 2005). Consequently, addressing new uses via new sources has been largely replaced by reallocation and conservation of existing supplies.

Irrigators are the largest water consumers in the American West; consuming roughly 80 per cent of fresh water. Urban, industrial and environmental users

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consume the remaining share. In the United States, irrigators have traditionally been heavily subsidised by the federal government; typically paying only the pumping and conveyances costs but not the scarcity value of water (Libecap 2007). Furthermore, a portion of the water applied to agriculture is toward the production of low-valued crops such as hay and alfalfa. At the margin, urban, environmental and high-valued crops uses have far greater water values. Therefore, a combination of scarcity and application in low-valued production creates an opportunity for markets to reallocate water to higher-valued uses. The development of water markets, however, has been slow to mature.

The aims of this paper are to explain why U.S. western water markets have been slow to form and why water trading is sometimes met with opposition. The unique physical properties of water make it a resource unlike most others. Consequently, creating property rights to water that are clearly defined, enforceable and tradable has unique challenges. This paper will also discuss the institutions that must be in place to create the incentives for a market in tradable water rights to work. It also uses a unique dataset of western United States water right transactions to illustrate price trends and differences in contractual forms used in water markets.

The paper is organised as follows. Section 2 describes the qualities of water that make it a unique resource and the challenges in defining and transferring property rights. The complexity and types of water rights are explained in Section 3. Section 4 describes the institutions involved in water markets. An example of the administrative transaction process is given in Section 5. Section 6 illustrates recent trends for United States water markets and breaks down transactions by contractual form. Concluding remarks are made in Section 7.

2. Water as a unique good

Assuming water is a scarce resource, we can describe it as an economic good (Chong and Sunding 2006). In economics, a Pareto optimal water allocation would be one that can make no person better off without adversely affecting another person. The efficient allocation therefore would be one that equates the marginal price of water across all uses, net of conveyance costs and adjusting for differences in water quality and priority of water right. In fact, this is not the result we find in U.S. water trading. Typically prices for water trades among agricultural users are much less than out-of-sector trades, say, to municipal or industrial uses. For example, some farmers in southern California's Imperial Irrigation District pay $20 per acre-foot of water while the city of San Diego has offered ten times that amount – $225 – per acre-foot for the same water (Murphy 2003).

Discrepancies in marginal water prices are, in part, a consequence of the complexity of defining water rights. Because water is not a standard commodity, various federal and state regulations govern the rights to own and transfer water. Multiple parties have a stake in water transfers, which are often contentious.

2.1 Bounding

As a fugitive (mobile) resource, water is not easily bounded. Unlike property in land, for example, rights to water are not allocated to claimants in partitioned stocks. Water's mobility does not allow for it to be easily excluded from other potential users. Water in rivers and streams often travels hundreds of miles and crosses many private and public boundaries. Surface water is also susceptible to evaporation and seepage into groundwater. Lakes and reservoirs are less affected by water mobility. Still, they are not easily partitioned into parcels. Making a claim to water, therefore, cannot be done in the traditional manner of capturing a resource, such as land. The costs of defining and enforcing property rights in water are unique and typically much greater.

In the eastern United States, where water is less scarce, there is less need to define a property right in water and thus less concern over non-excludability. In the western United States, though, quantifying a water right is very important. Instead of particular stocks, water rights are assigned to flows of water. The standard unit of measurement is acre-feet per year (AF), which is the volume to cover one acre with one foot of water, or 325 851 gallons.

2.2 Measurement

Another layer of complexity is added when considering how an acre-foot allotment of water is measured. Depending on the use, surface water may be reused by other water right holders. The distinction is between the quantity of water diverted and the quantity consumed.

In agriculture, for example, the amount of water diverted is the amount removed from a stream and used in the production of crops or livestock. The diversion amount is observable and therefore not difficult to measure. Seasonality and drought, however, can affect the amount of water that is available for diversion. This leads to uncertainty in the amount of water that is available. In markets that transfer rights to water, it may be difficult to forecast whether a water source will be able to fulfil a water commitment. The issue is of such great importance, in fact, that 'paper water' and 'wet water' are terms of art that have been coined to describe the concerns of water availability and over-appropriation (Howitt 1998).

Another important measurement of water use is actual consumption. Especially in agriculture, the amount of water diverted is often less that the amount consumed by crops. The unconsumed portion of diverted water continues in the hydrologic cycle in various other ways, such as through evapotranspiration, groundwater storage and runoff. Diverted water that makes its way back to streams and groundwater supplies has important consequences for other water claimants. These return flows can be recaptured and used again. Depending on the use, in some areas up to 50 per cent of a water diversion can be recaptured (Young 1986). So, downstream water

claimants may dependent highly on the timing and nature of upstream users' water diversions.

Relative to diversion, measuring water consumption is much more costly (Heller 1998). Topography, geology, and hydrology all affect the speed and movement of water. In transferring water rights, however, consumption is more important for determining the quantity of water that can be traded without adversely affecting other claimants. Most western states define the transfer of a water right to be a change in the timing, location or use of water. One or more of these changes can affect return flows and thus other water claimants. This is considered so important, in fact, that Colorado water law forbids the capture of rainwater from rooftops because of its potential impact on water claimants (Philipps 2007). Clearly defined water rights are necessary, therefore, to reduce conflict among claimants and to set up water markets and institutions that provide incentives for voluntary trade.

Defining and enforcing property rights in water, as discussed above, is costly. Measuring consumption and excluding other claimants is important because of the sequential or simultaneous uses of water. These uses create interdependencies between claimants, who must be aware of how water is used in aquifers, reservoirs or streams. This is most important when water rights are created or traded. To guard against a reduction in water availability and quality, claimants' surface water rights are protected in the western states by 'no injury' rules (Gould 1989). As the phrase suggests, no injury rules guard against third-party effect of water transactions. Meeting this requirement means that most transactions are limited to the estimated consumed amount rather than the total divertible amount assigned to a water right.

A system of water rights governance must be established to arbitrate disputes over claimants' rights and reach consensus over proposed reallocations. For claimants, seeking approval and resolving disputes over proposed water transfers can have high transaction costs. These high costs and barriers to trading create an 'anticommons' problem, where transaction costs, holdouts, rent-seeking or onerous regulations may impede trade to higher and better uses of water (Heller 1998).

Overcoming these barriers to trade is possible when water rights are clearly defined, enforceable and transferable. Establishing political and legal institutions that support a clear definition of property rights in water lowers transaction costs and facilitates the development of water markets and water resource investment.

3. Systems of U.S. water rights

Various systems of water rights were adopted in the United States over time to address scarcity and competing water allocations. The three main types of U.S. water rights are appropriative, riparian and groundwater rights. In all systems, claimants may hold only the usufruct right, while ownership of the water is held by the state.

3.1 Appropriative doctrine

The appropriative doctrine or, as it is more commonly referred, the doctrine of prior appropriation is a queuing system that rewards first movers. Prior appropriation was adopted first in the western United States in the 1850s by miners who appropriated surface water for sluicing (Anderson and Hill 1975). Then, as today, there was less water available than demanded, so an allocation scheme was developed on the notion of 'first in time, first in right.' This seniority system establishes water rights by the sequential order that claimants appropriate water. This is known as the rules of first possession (Rose 1985; Lueck 1995). In this system, the first claimant to a water source has the highest priority to divert water, so long as the withdrawal is for a 'reasonable and beneficial use.'

Other claimants may appropriate water from the source and establish a water right with a priority date junior to the claimants who came before. Rights continue to be established until a water source is fully appropriated. In times of drought or when a river or stream is over-appropriated, water is allocated by the seniority of the water right; meaning a junior right holder will not receive his or her allocation until the allocation rights of the senior are met. The implication in the prior appropriation system is that the expectation of water delivery increases with the seniority of a water right's priority date.

Water rights with older priority dates are more likely to receive their full allocation and hence are more valuable; this is the distinction between 'wet rights' and 'paper rights' discussed earlier. Relative to junior priority rights, then, senior water right holders are more certain to receive water delivery and thus have more incentive to invest in water production (Libecap 2007). As it stands in the United States, agricultural users have typically held the more senior water rights; irrigators having outlasted mining interests and entered the western United States before significant population centres and environmental interests began appropriating water rights (Kanazawa 1998).

As said before, water right holders possess only usufruct rights; states retain title to the corpus of the water. This legal arrangement weakens water rights by making them less secure. Claimants can lose a water right several ways, including through waste and forfeiture. Wilfully wasting water is usually defined as diverting water beyond what is considered reasonable and beneficial. Water lost to irrigation canal seepage or evaporation is not considered wasteful if it is consistent with customs of the locality (Ruml 2005). When water loss is egregious by local standards, however, it may be considered wasteful. In most states, the regulating agency governing water rights establishes an irrigation 'water duty' that determines the amount of water that can be used without constituting waste (Glennon 1991).

Like rules against wasteful water use, forfeiture rules are designed to prevent speculation in water rights and encourage productive uses of water by deterring non-use. The forfeiture rule, often known by the maxim 'use it or lose it,' states that if a portion of a water right is not used for a period of

consecutive years, then that portion of the water right is assumed to be forfeited and is subject to cancellation by the regulating agency. The number of years of consecutive non-use varies by state. In Colorado water rights may be cancelled after 10 years of non-use; in Oregon five consecutive years is enough to assume forfeiture.

This rule, however, does not apply in all circumstances of a water right going unused for a period of time. For example, a period of drought or a water right with a low priority date may render water unavailable for a period of time, in which case it would not be considered forfeiture. Also, many farmers participate in federal and state programs to fallow cropland or leave water instream for environmental use; these programs are also exempt from the forfeiture rule (OWRD 2008).

The well-developed appropriative water rights doctrine in the U.S. west is a basis for water markets. The doctrine allows for water to be claimed, diverted and separated from the land through which the water flows. It can be transported out of basin for use elsewhere. As such, those who buy water rights or lease water can change the location of diversion, timing of use, and nature and site of ultimate use, subject to regulatory approval to protect downstream claimants. With riparian water rights, however, both the land and the water generally have to be purchased if the water is to be used in another manner and the stream flow cannot be seriously impacted.

3.2 Riparian doctrine

The 98th meridian is the symbolic line that divides rainfall and water availability in the United States. West of the 98th meridian the average rainfall is less than 20 inches per year, which is the amount regarded as necessary to grow crops reliably (Merchant 2002). East of the meridian rainfall is less erratic and averages over 30 inches per year. The four largest rivers by average discharge are in the eastern United States. By contrast, the fifth largest U.S. River – the Missouri – carries only one-third the volume discharged by the Columbia River (fourth largest) and 13 per cent of the Mississippi (Kammerer 1990).

The abundance of rainfall and available water in the eastern United States reduces the need to adopt an appropriative water doctrine to divert water far from water sources. Historically, eastern water was used in power generation, which is largely non-rivalrous in that water used at one point on a stream would be available for use again farther downstream (Rose 1990). Though there are consumptive, rivalrous water uses in the East, the lower scarcity of water has meant that the English common law doctrine of riparian water rights has been retained. Like appropriative water rights, riparian rights are usufruct; however, riparian rights run appurtenant to the land adjacent to a surface water source. Riparian land owners can access water for a 'reasonable use,' so long as downstream users are not adversely affected. Unlike appropriative rights, riparian rights cannot be forfeited from non-use and they are

not assigned priority dates. In times of drought, all riparian users share in the reduced water availability.

As mentioned above, the riparian doctrine is inadequate for the consumptive water uses of the semiarid West. Most western states, such as Colorado, dropped the riparian system in favour of the appropriative doctrine. Some states, such as California, have adopted a hybrid system of riparian and appropriative rights.

3.3 Groundwater rights

Groundwater rights vary greatly across states. Differences in recharge rates, interaction with surface water and the size of groundwater basins makes groundwater rules difficult to apply across the board. Moreover, the groundwater rules that are in effect are costly to enforce (Thompson 1993). Groundwater is unobservable and more difficult to measure and monitor extractive use. In some states, including parts of Texas, unlimited ground water pumping is allowed by a landowner so long as it is put to a beneficial use (Howe 2002). In general, groundwater rights are much less precisely defined than are surface water rights. Groundwater is more like an open-access resource, subject to wasteful extraction (Glennon 2002).

4. Water institutions and policies

Although water right holders are the main parties to usufruct right claims, there are various water institutions that influence water allocation. These institutions may be public or private and may have considerable influence in the delivery and enforcement of water rights. The institutional arrangement and incentives they face may also influence the development of water markets.

4.1 State agencies

Water agencies are the main regulatory bodies charged with administering state water laws. Authority is vested in the State Engineer in New Mexico and Utah, the State Water Resources Control Board in California or the Department of Water Resources in Oregon and Arizona to name a few agencies. These agencies monitor stream flow to ensure instream quantity requirements are met, enforce water rights by issuing orders to junior water right holders to curtail diversion when water availability is over-appropriated and approve water right transactions.

The role of the state agency in water transactions is to review the application to ensure that third-parties will not be injured and that the change in use, time or place does not 'enlarge' the water right. These agencies also enforce laws that limit water markets, such as restrictions on the duration of leases or limiting transfers to predetermined 'beneficial uses.' For example, it was not until 20 years ago that western states began recognising instream flows as a

beneficial use. As Section 6 shows, a considerable amount of water is today transferred to environmental uses.

4.2 Bureau of Reclamation

The largest wholesale provider of water in the United States is the Bureau of Reclamation. Established through the Federal Reclamation Act of 1902 to promote westward expansion and agriculture, the Bureau operates 348 reservoirs in the 17 western states and also operates canals and hydroelectric power plants. The Bureau supplies water to 31 million people and irrigation water to 140 000 farmers on 10 million acres of land (Bureau of Reclamation 2008). The Bureau most often delivers water through 'retailing' institutions such as mutual water companies and irrigation districts (Thompson 1993). Typically, the water rights are held by the Bureau and contracted to the water districts (Wahl 1989). Transferring Bureau water entitlements by water districts is allowed, however, the policy has not been consistent and transfers usually require approval by the agency (Thompson 1993).

4.3 Water supply organisations

Water supply organisations were first formed in the late 19th to invest in large-scale water infrastructure such as diversion dams and irrigation ditches. Today there are over 1000 supply organisations in the western United States. Most organisations are legally constituted governmental entities that have the power to tax levies on land and charge for water and delivery (Rosen and Sexton 1993). These organisations include irrigation districts, mutual ditch companies, conservation districts and water companies. Typically, these organisations act in a trust capacity on behalf of their members; however, their governance styles and voting rules vary greatly.

Irrigation districts are the most common type of water supply organisation. In most irrigation districts, the water rights are controlled by the district and then contracted amounts are delivered to members. For all users then, the priority of the water right is the same and allocation based on an agreed upon mechanism.

Selling and leasing water rights outside an irrigation district usually requires approval from the district board and is met often with opposition. Thompson (1993) offers several reasons why external trades might be opposed. One is that property rights are not clearly defined in irrigation districts. Therefore, who should receive the financial benefits from water rights transactions is often disputed. Another reason transfers are said to be opposed is because they are counter to the interests of the other district members. Out of district transfers may undermine the district's finances, raise costs or increase the price of water. One final possibility is that managers or district boards are resistant because of administrative concerns or political pressures. Here, managerial decisions are likely to be influenced by their

voting constituencies. In districts where voting is restricted to landowners, the incentives of managers and boards are more likely to be aligned with their members. On the other hand, where all registered voters living in the district have an equal vote, farmers and irrigation boards may face different incentives.

5. Water transactions

A water right may be certified only for a particular place of use, point of diversion and type of use. To change any of these restrictions requires that the governing agency approve the transfer. These transfer rules typically hold for both temporary and permanent water transfers, although they are much stricter for rights sales and long-term leases. Short-term leases may take place within irrigation districts, for example, without regulatory approval because there are few externalities.

An applicant must submit an application to the governing agency describing the proposed change in the current water right. In some states, the applicant may have to hire a certified water rights examiner to study the water use and file a report with the agency detailing the current water use. The agency must then determine that no other water right will be injured by the proposed change, and they will also study whether the change will negatively affect fish, wildlife and other instream users. The no injury requirement typically means that a water transfer is limited to the historical consumptive use of the right. This is an important point because any portion of the water right that is not transferred to the new use may be lost and reverted back to the state (OWRD 2008). For example, to prevent injury to other diverters a water right of 10 acre-feet may only be able to transfer a consumptive use of 6 acre-feet. The remaining 4 acre-feet would be forfeited by the transferor to sustain those who relied upon it downstream.

A public announcement of the proposed trade is made, usually printed one or more weeks in a newspaper, and a comment period is opened to allow the public to raise objections to the transfer if they believe a water right will be injured (Ruml 2005). If the transfer is protested, a hearing is held by the agency or a water court and both sides present their cases. If there is potential injury, the agency or court accept or deny the application, or may attach conditions, such as a reduction in the total water transferred, to an approval order to eliminate injury to other water rights. If a transfer is approved, then the agency will issue a new water right certificate reflecting the permanent change in water use.

Depending on the criteria required for status, the range of grounds for contesting a transfer, and the information requirements that are placed upon the protester (and these vary by state), the application process can take well over a year to complete in some cases. Once a change is made to a water right certificate, it cannot be cancelled or repealed. If a water right injury is discovered after the certificate for a new water use is issued, there is no recourse for other water claimants.

In circumstances where a transfer of water is temporary (not a sale of the right), which is most commonly a lease, approval times may be shorter because other water rights are not in jeopardy. In Oregon, for example, the water resources department does not issue a change in the water right certificate for a temporary transfer of water through short-term leases. Instead, the water reverts back to its original use after the lease period expires. This arrangement allows the department to review applications and approve or deny transfers, while retaining the ability to revoke an application if the change results in injury to other water rights (OWRD 2008). The flexibility of this rule allows for faster approval times of temporary transfers – an average of 30 days – and reduces the time costs of waiting for the approval of an application.

Temporary water right transfers can be further limited in the types of transfers allowed. Some states restrict temporary transfers to place of use and point of diversion; not permitting changes in the type of use, say, from agriculture to urban uses. Temporary transfers are often limited in duration as well. Oregon does not allow temporary transfers beyond five years. California breaks up temporary transfers into two parts, short-term and long-term. Short-term transfers are used to meet urgent needs and can be expedited, similar to Oregon's rules, but are limited to one-year in duration. Long-term transfers are not limited in duration but must meet the same lengthy application and protesting procedures that permanent transfers do (State Water Resources Control Board 1999).

6. U.S. water trading

To examine patterns of water trading in the United States, I extend transaction data first assembled by Brewer *et al*. (2008) from the *Water Strategist*. The *Water Strategist* is a monthly trade publication that reports on western water market activity, state and federal legislation, and litigation. Each month, they publish a section titled 'Transactions' that reports on sales, leases and exchanges of water rights. The transactions are listed by state and report some or all of the following information: buyer and seller; contract type, such as sale, lease or exchange; quantity of water transferred; water use, such as municipal, agricultural or environmental; and price.

The dataset spans a 21-year period from 1987 to 2007 and include 3387 observations from Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Wyoming and Washington. There is no doubt that the dataset misses some transactions. These are likely to be transactions that occur within an organisation, such as a ditch company or irrigation district. Still, this is the most comprehensive data available on water markets across the western United States.

Table 1 describes prices for water transfers by sector and contract type. To compare prices across the 21-year period, all price data were converted to 1987 dollars. Mean and median prices are given in dollars per acre-foot for

Table 1 Water transfer prices per acre-foot, 1987–2007

	Leases				Sales			
	Agriculture-to-agriculture	Agriculture-to-environment	Agriculture-to-urban	Urban-to-urban	Agriculture-to-agriculture	Agriculture-to-environment	Agriculture-to-urban	Urban-to-urban
Mean price ($)	36	126	424	279	2362	2565	4552	2816
Median price ($)	11	32	56	123	1451	552	2896	1234
Number of transfers	206	184	207	119	196	52	1097	182

Source: Brewer *et al.* (2008); *Water Strategist*.

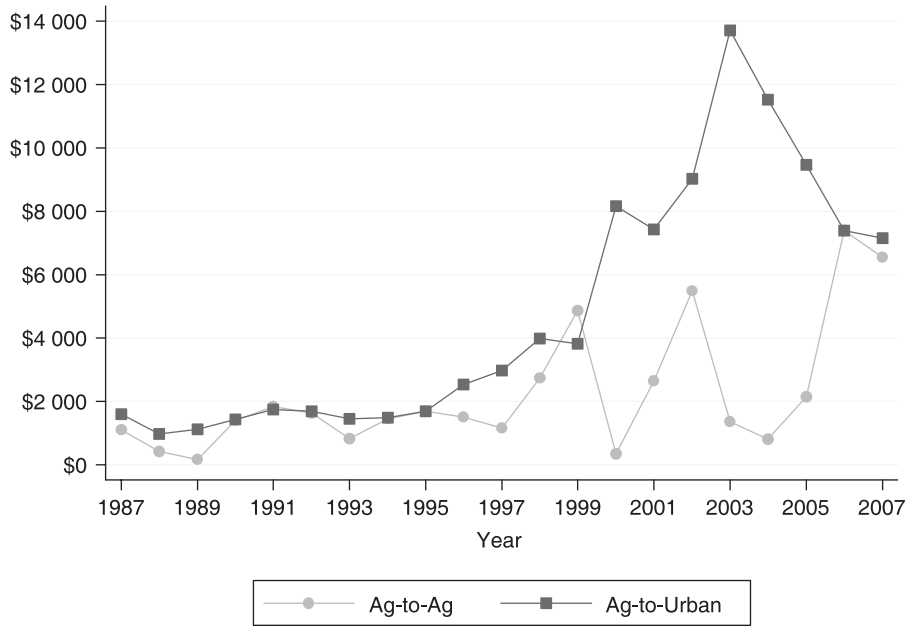

Figure 1 Median sales prices per acre-foot, 1987–2007.

the four most common sectors water is traded: agriculture-to-agriculture, agriculture-to-environment, agriculture-to-urban and urban-to-urban. These sectors represent 89 per cent of 2530 transactions that include price data. Lease prices are reported in terms of annual flows per year. Sales on the other hand represent perpetual right an annual flow of water, as reflected in the higher prices they command. The mean and median lease prices for agriculture-to-agriculture transfers are significantly lower, using a Wilcoxon signed-rank test at 5 per cent significance level, than the other trading sectors, which in part is an indication of the relatively lower value of water in agriculture at the margin.

Figure 1 represents the annual median sales prices per acre foot for agriculture-to-agriculture and agriculture-to-urban sector water transfers. Using a Wilcoxon sign rank test, the differences in median sales prices is significant at the 5 per cent level. Sales data are driven largely by transaction in one state. 72 per cent of the 2410 sales originate in Colorado. This is due to the institutional structure of the Colorado Big-Thompson Project (C-BT) and the sole irrigation district within the water project – the Northern Colorado Water Conservancy District – that make water rights uniform, reduce third party effects, and accordingly make transfers much easier (Carey and Sunding 2001; Brewer *et al*. 2008). The Colorado Big-Thompson institutional arrangements may be more like those used in Australia for water entitlements and allocations (see Young and McColl paper in this volume).

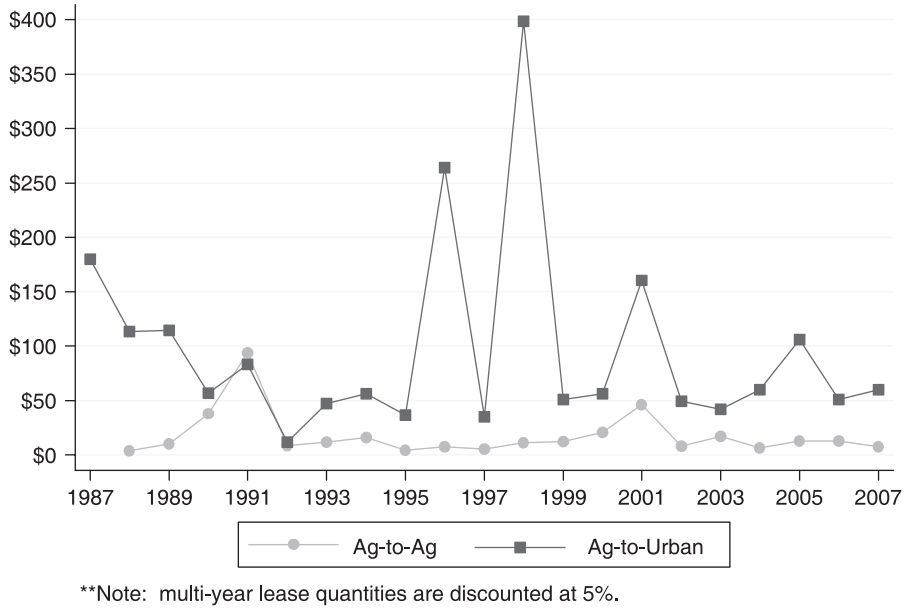

Figure 2 Median lease prices, 1987–2007.

Figure 2 shows the median lease prices from 1987 to 2007 for agriculture-to-agriculture and agriculture-to-urban sector trades. As with the median sales prices, agriculture-to-urban leases are significantly higher in price than agriculture-to-agriculture leases.

There are several types of contractual forms available for trading water: sales, short-term and long-term leases, and exchanges. Exchanges occur usually when developers donate water rights to a city as part of agreements to secure water supplies. In the *Water Strategist* dataset these exchanges represent less than 1 per cent of transfers. Figure 3 plots the most common contract types over time; breaking down leases to one-year and multiyear. Over time, the total number of annual transactions is trending upward with a significance level of 5 per cent, using a Wilcoxon signed-rank test. Sale and multiyear leases also have a significant upward trend. One-year years have a non-significant trend. To further examine leases, Table 2 shows that short-term leases are the dominant contract form, involving 76 per cent of the total. Also, the average size of a transaction in acre-feet for one-year leases is larger than for multiyear leases. One-year leases generally are used within sectors, among farmers for instance, to adjust temporary water requirements.

Table 3 describes water transactions by contract type and the most common sector-to-sector trades. The average quantity of water traded is broken down into two distinct measurements: the annual flow and the committed flow of water. The annual flow measurement is the traditional way of defining the volume of water traded. It describes the amount of water transferred in any one year

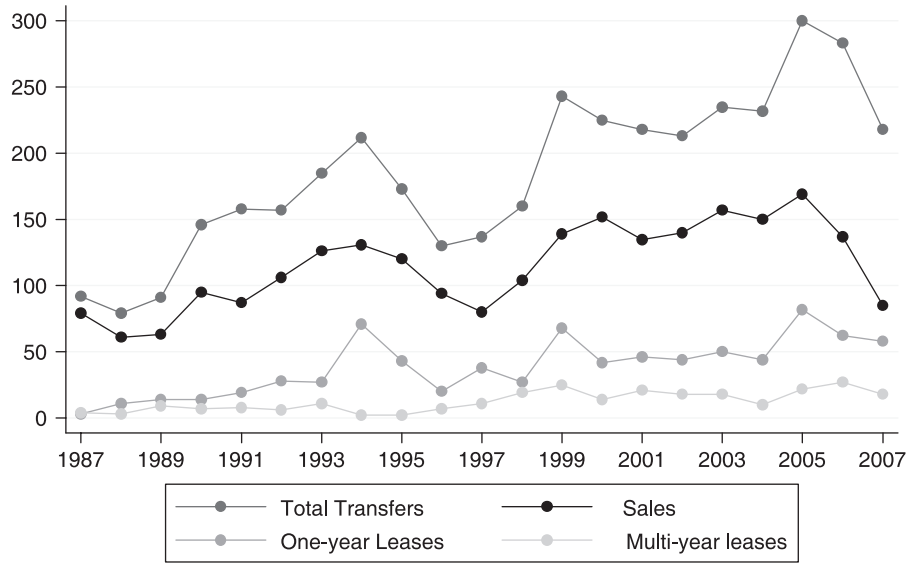

Figure 3 Water transfers by contract type, 1987–2007.

Table 2 Lease durations

Duration (years)	Number	Frequency (%)	Average size (AF)
1	811	76	27 859
2–5	77	7	11 484
6–9	7	0	3 709
10–19	47	4	7 662
20–29	44	4	5 065
30–39	21	2	14 129
40–49	28	3	9 535
50–74	10	1	50 086
75	18	2	1 613
100	9	1	14 632
Total	1072	100	23 734

Source: Brewer *et al.* (2008); *Water Strategist*.

of a transaction. The downside to this measurement is that it substantially underreports the total amount of water transferred in sales and multiyear leases.

Following Brewer *et al.* (2008), I include a measurement for the committed water flow. The committed variable overcomes the underreporting problem by projecting the annual flow forward for the duration of the lease or, in the case of sales, in perpetuity. The committed variable is calculated by discounting the annual flow by 5 per cent per year and then summing the series of years. The resulting measurement is the amount of water committed for the duration of a transaction.

Table 3 Water transactions by contract type and sector, 1987–2007

	Agriculture-to-urban	Agriculture-to-agriculture	Urban-to-urban	Agriculture-to-environment	Agriculture-to-urban	Agriculture-to-agriculture	Urban-to-urban	Agriculture-to-environment
	Number of transfers				**Number of transfers**			
Sales	1 667	248	304	85	1667	248	304	85
Leases								
One-year	154	205	96	174	154	205	96	174
Multi-year	97	28	58	44	97	28	58	44
	Committed average size (acre-foot)				**Annual flow average size (acre-foot)**			
Sales	19 744	34 942	41 731	119 448	987	1 747	2 186	5 893
Leases								
One-year	16 910	28 833	43 482	32 005	16 910	28 833	43 482	32 005
Multi-year	91 701	36 433	212 115	69 741	7 601	3308	14 364	10 043

Source: Brewer *et al*. (2008); *Water Strategist*.

Table 4 Water transfers by contract type, 1987–2007

			Committed		Annual flow	
	Number of transfers	Frequency (%)	Amount (acre-foot)	Frequency (%)	Amount (acre-foot)	Frequency (%)
Sales	2410	66	89 423 347	59	4 503 256	14
One-year leases	811	22	22 593 941	15	22 593 941	73
Multi-year leases	261	7	30 473 836	20	2 695 579	9
Exchanges	193	5	9 688 280	6	1 210 651	4
Total	3675	100	152 179 404	100	31 003 427	100

Source: Brewer *et al*. (2008); *Water Strategist*.

Table 3 indicates that agriculture-to-urban sales (1667) are the most common transfers. Relative to the other categories, agriculture-to-urban sales are also less in size in terms of flows. These transactions are likely smaller because they change the water use and therefore have to meet regulatory requirement and protect against third-party injury. They also reflect the many small sales transactions within the Colorado Big-Thompson Project.

Agriculture-to-Environment sales (35) were fewer in number than all other sectors, but they were also much larger in terms of flow than all other sales. These often are in response to court mandates. One-year leases are the most numerous of agriculture-to-environmental sector transfers (174).

Agriculture-to-agriculture transactions are split evenly between sales and leases, at 248 and 232, respectively. Sales are small with an average annual flow of 1747 acre-feet; however, committed flows are much larger at 34 942 acre-feet.

Across all sectors multiyear leases are fewer in number than sales or one-year leases. Interestingly, when the urban sector is the destination user, multiyear leases are much larger on average in terms of committed and annual flows than sales.

The value of including the committed flow variable is shown in Table 4's summary of water transactions by contract type. Two-thirds of all transactions during this 21-year period are in the form of permanent transfers. Described as annual flows, sales account for only 14 per cent of traded water. When measured as the amount of water committed over time, however, we see that sales represent 59 per cent of the total acre-feet transferred. Leases, which are shorter in duration and are on average larger in volume, have the opposite relationship. Leases represent 29 per cent of transfers, 81 per cent of annual flow and 35 per cent of committed flow.

Table 5 details water transfers by sector from 1987 to 2007. 'Combination' represents transactions that have more than one original or new use. Agriculture is the origin of 79 per cent of all trades and represents 62 per cent of annual and 50 per cent of committed flows. Fifteen per cent of all trades are agriculture-to-agriculture, which represent 22 per cent of annual flows and 10 per cent of

Table 5 Water transfers by sector, 1987–2007

Classification	Number of transfers	Frequency (%)	Amount (acre-foot)	Frequency (%)	Amount (acre-foot)	Frequency (%)
Agriculture-to-agriculture	550	15	16 695 742	10	7 366 449	22
Agriculture-to-urban	2065	55	47 343 684	30	5 945 552	18
Agriculture-to-environment	333	9	21 827 100	14	7 421 801	22
Urban-to-agriculture	44	1	5 284 045	3	360 499	1
Urban-to-urban	503	13	29 728 809	19	5 919 701	18
Urban-to-environment	58	2	8 943 008	6	1 071 594	3
Environment-to-agriculture	0	0	0	0	0	0
Environment-to-urban	1	0	62	0	62	0
Environment-to-environment	8	0	4 231 488	3	344 574	1
Combination	208	5	23 400 915	15	5 247 415	15
Total	3770	100	157 454 853	100	33 677 647	100

Source: Brewer *et al.* (2008); *Water Strategist*.

water measured as committed flow. Agriculture-to-urban trades comprise a majority at 55 per cent. They contribute 18 per cent of annual flows traded and 30 per cent of committed water.

The agriculture-to-environment sector comprises 9 per cent of trades, 22 per cent of annual flows and 14 per cent of committed water. The difference between the committed amount and the annual amount shows that one-year leases are used more often in agriculture-to-environment transfers, often to augment stream flows. Similarly, agriculture-to-agriculture trades represent a greater proportion of annual flows (22 per cent) than committed amounts (10 per cent). These results are explained partially by the short-term needs of the destination users, who seek to fill a short-term demand brought on by a water shortage or drought.

7. Conclusion

Systems of water rights in the United States are complex and reflect the unique physical properties of water that make it difficult to measure, capture and trade. This paper shows that the size and frequency of water rights transfers in the western United States is increasing over time. As in many parts of the world, the semi-arid American West faces water scarcity issues amongst heterogeneous and competing users. Solving these issues through augmentation is no longer viable as it was in the last century. That agricultural water users are by far the dominant water right holders with typically the most senior priority dates creates opportunities to move water from lower-valued agricultural uses to higher-valued urban, recreational and environmental uses. The interdependencies amongst water users, however, place limits on

the ability to transfer water rights in terms of timing, type and location of use. In spite of this, states have developed institutions and regulations that permit water trading in varying degrees.

Data collected from the trade journal *Water Strategist* show relative pressure to reallocate water from the agriculture to urban sector. Consistent with Brewer *et al*. (2008), the data show that agriculture-to-urban sector sales are the dominant form of trade in terms of number of transfers. Moreover, the rate permanent transfers is increasing over time; an indication of preferences for longer term security of a water claim. Prices are also significantly higher for urban use relative to agriculture.

Important details of water trading are also revealed when examining the different measures of quantity. While permanent water transfers represent only a small percentage (14 per cent) of annual water flows over the 21-year period, they constitute 59 per cent of water committed in a transaction over time. Conversely, one-year leases make up 73 per cent of annual flows traded but only 15 per cent of water committed over time. Breaking down these results by sector, we see that trades to urban users constitute nearly half of all water flows obligated over time. Meanwhile, agricultural and environmental users acquire a larger share of annual flows due to dominance of one-year leases in these sectors.

Of the total water diverted in the western United States, only a small fraction is currently being traded. The large range of prices paid for water suggests there are many more opportunities for trading. Water markets can be a vehicle for reallocating water to new and higher-valued uses if rights are clearly defined and transaction costs are low. Within the appropriate water right system, adjudicated rights provide legal clarity to water right holders, which reduce disputes over competing claims and makes third-party injuries easier to determine and avoid.

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