Mechanisms for Addressing Third-Party Impacts Resulting from Voluntary Water Transfers

Running title: Water markets and third-party impacts

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**Mechanisms for Addressing Third-Party Impacts
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Abstract

This paper uses laboratory experiments to test different water market institutions designed to protect third-party interests. The institutions tested include taxing mechanisms that raise revenue to compensate affected third-parties and a market in which these third-parties actively participate. The results indicate that there are some important trade-offs in selecting a policy option. Active third-party participation in the market is likely to result in partial free riding that may erode some or all of the efficiency gains, and may introduce volatility into the market. Taxing transfers and compensating third-parties offers a promising balance of efficiency, equity and market stability.

Keywords: arbitration, experiments, third-party impacts, environmental impacts, water markets, water transfers

Introduction

Voluntary transfers have emerged as a central instrument in balancing and reallocating the changing demand and supply for water in the Western United States. These transfers can have significant impacts beyond the benefits realized by the parties engaged in the voluntary transfer, such as environmental degradation due to reduced streamflows or regional economic impacts in the source areas. A viable water transfer mechanism must incorporate not only the direct benefits and costs associated with the transfer, but also the external costs imposed on the environment and local communities. Until it can be demonstrated that a water market institution is capable of adequately accounting for environmental and regional economic impacts, voluntary water transfers will not realize their full potential as an integral part of a comprehensive water management strategy.

We use laboratory experiments to test alternative water market institutions designed to incorporate the value of non-consumptive water uses into the allocation process. A non-consumptive water use includes any activity that derives an economic benefit from the water without actually consuming it. For example, water consumed in an agricultural region may stimulate local economic growth and water flowing instream may provide water quality and environmental benefits. This research was initially motivated by California's objective of avoiding unreasonable disruptions to the local economy in the source areas, which we refer to as third-party impacts. Because these impacts are pecuniary externalities and may be the result of a well-functioning market, some economists might find it troubling to impose restrictions on voluntary exchange in order to protect these third-parties. Below, we make the case that, although perhaps unorthodox, the protection of rural economies is an unavoidable reality and any exchange mechanism that ignores these consequences is not viable. More importantly, we emphasize that although the focus of this chapter is on third-party impacts, the results and analysis are applicable to any non-consumptive water use. This includes the environmental benefits of instream flows, which most economists would agree are a classic externality problem that ought to be incorporated into water allocation decisions.

Concern about the social and economic impacts from water transfers has a long history in California and exerts a strong influence on policy decisions today. Memories of Owen's Valley still persist and resistance to water exports can be strong, particularly in some rural areas. Section 1745.05 of the state's Water Code restricts exports to 20 per cent of the local water supply, and 22 of the state's 58 counties have imposed restrictions on groundwater exports (Hanak 2003). Hanak suggests that these local ordinances reflect a broader intent to discourage any type of transfer that might affect the local economy. Moreover, extensive idling of crops that results in unemployment of manual laborers could be considered an unfair treatment under the state's environmental justice policies (California Department of Water Resources 2004) and some environmental justice representatives have argued that the public trust doctrine includes broader economic and social concerns (Water Transfer Workgroup 2002). A recent report for the State Water Resources Control Board (SWRCB) asserts that the highly subsidized rates that agriculture pays for water reflects the high value society places on agriculture, and that this objective could be undermined if water does not remain with its intended use. They therefore recommend that water exports must avoid unreasonable impacts on the overall economy from the source area (Water Transfer Workgroup 2002). Recognizing the need to minimize these impacts, a recent agreement between the Metropolitan Water District of Southern California and the Palo Verde Irrigation District includes a $6 million payment to the community to offset economic harm from land fallowing (Vogel 2002).

Non-consumptive rights are often protected by constraints on water transfers such as minimum instream flow requirements, taxes on transfers, restrictions on the quantity of water that may be exported from a region, or “no injury” rules. When constraints on transfers are binding, the resulting allocation will be inefficient (Weber 2001). Both Huffman 1983 and Griffin and Hsu 1993 suggest that the creation of property rights for non-consumptive use may lead to more efficient allocations. Since the externalities associated with water transfers vary by location, efficiency will usually require location-specific pricing (Griffin and Hsu 1993; Weber 2001). However, a water market with spatially discriminative prices is likely to be complex and face high transaction costs associated with finding trading partners. Thus, institutional design plays an important role in the transmission of information and the evolution of prices such that the water market yields efficient allocations (Weber 2001).

Successful implementation of an institution that can facilitate water transfers requires a substantial amount of coordination to achieve an efficient water allocation, especially in the presence of nonconsumptive uses. The SWRCB observed that an efficient water allocation must balance an “unusually complex mix of price responsive and non-price responsive social values” including complex interrelations between the multitude of consumptive and non-consumptive uses (Water Transfer Workgroup 2002). They concluded that market forces alone cannot achieve efficient allocations because of the inherent complexities and externalities not considered during private bargaining.

However, advances in computing technology and high-speed communication networks can facilitate exchange systems in complex environments that were previously considered impractical. ‘Smart,’ computer-coordinated markets can provide a decentralized solution to complex resource allocation problems. McCabe, et al. 1989 and 1991, have demonstrated the ability of these ‘smart’ markets to achieve efficient allocations in the natural gas and electricity industries. Dinar, et al. 1998 and Murphy, et al. 2000 report similar success applying the ‘smart’ market concept to spot water markets with environmental constraints. These ‘smart’ markets allow participants to submit bids to buy and offers to sell to a centralized computer center. Using the willingness to exchange provided by participants, the ‘smart’ market can then compute prices and allocations by maximizing the gains from trade subject to physical constraints on the system (for example, streamflow or reservoir capacity). By doing so, these markets can lower transaction costs, facilitate trades that may not have otherwise been effected, and increase overall market efficiency. The ability of these electronic markets to address complex allocation problems is a particularly attractive feature for water markets, especially in the presence of environmental and third-party impacts.

Murphy, et al. 2004 find that computer-assisted markets can successfully incorporate instream flow values into the water allocation mechanism. Their results indicate that facilitating direct environmental participation in the market can yield highly efficient outcomes, although it may introduce some volatility. Although motivated by the protection of instream flow values, their results are equally applicable to any nonconsumptive use including third-party impacts. The research in this chapter extends their analysis by considering a mechanism that decouples the water allocation decision from the compensation of non-consumptive users adversely affected by water transfers. During droughts, rapid approval of short-term transfers is critical and there may be inadequate time for a lengthy review process to quantify third-party or environmental damages. To account for this, the Model California Water Transfer Act (Gray 1996) proposes a tax-and-compensate scheme to expedite transfers. The basic process is simple: a regulator sets the tax rate at the beginning of the water year and trading occurs with participants paying the tax on all water transfers. Tax revenue goes directly into a fund that is managed by a neutral arbitrator. At the end of the water year, victims of a water transfer may file a claim requesting compensation from the fund and the arbitrator renders a binding final decision to each claimant. Any surplus or deficit in the fund after compensation is carried over to the next water year.

This paper describes a series of laboratory experiments designed to test this compensation mechanism and compares it to an alternative institution that allows direct third-party market participation. The key results are: (1) although third-party participation in the market has the advantage of allowing those affected by the transfers to express their willingness-to-trade, it is prone to strategic behavior and free riding that may introduce market volatility and could erode the efficiency gains; and (2) taxing transfers to compensate victims as described above may not be able to maximize total social welfare, but the market still yields highly efficient and stable outcomes, and is more flexible than fixed limits on water transfers. Although further research is necessary, a tax on water transfers is a promising means of promoting highly efficient allocations while ensuring that third-parties are fully compensated.

Experimental design

In this paper, we use a controlled, laboratory setting to test three different water market institutions designed to account for third-party impacts. The first alternative facilitates direct third-party participation in the allocation mechanism. The last two institutions tested in this paper incorporate taxes on water transfers to compensate victims. We assume that third-parties derive a benefit from water consumed in their region (alternatively, an environmental benefit from instream flows at a particular location). Higher levels of water consumption imply increased regional economic activity. Similarly, exporting water out of a region generates third-party damages. We assume that third-parties know with certainty the level of damages associated with a proposed set of water transfers. However, because of the need for rapid approval of transfers during droughts, government regulators do not have this information until after the transfers have been completed and the damages have been realized.

Alternative 1: Third-parties participate in the water market (3PBuyer)

The first alternative, denoted 3PBuyer, tests a market structure that allows third-parties to actively participate in the water allocation process. In this institution, the third-parties do not have property rights to the water, but can participate in the market by subsidizing water consumption in their region. These third-party payments will increase the flow into the region thereby reducing adverse economic impacts. This institution is consistent with the observation that some environmental groups and private parties have been active in acquiring water to provide instream flows (Anderson and Snyder 1997; Landry 1998). Because the nature of third-party participation in this institution is identical to one of the environmental participation treatments in Murphy, et al. 2004, it serves as a link between the two studies.

Since third-parties best know their own circumstances and willingness to trade, if all agents were to truthfully reveal their true willingness-to-trade, then this institution would yield the maximum possible gains-from-trade, including nonconsumptive values. However, third-parties receive a benefit for any water consumed in the region regardless of whether they contribute to its provision. Because of the public good nature of non-consumptive water uses, there is an incentive for third-parties to under-contribute. Murphy, et al. 2004 observe that some demand under-revelation by nonconsumptive users exists in this institution, but not the pure freerider outcome predicted by theory. In addition, they observe more price volatility relative to a baseline with environmental constraints but no active environmental participation.

Alternatives 2 and 3: Water transfer taxes and third-party compensation

The California Model Water Transfer Act provides the basis for the two taxing mechanisms. Under the proposed Act, all short-term water transfers are allowed to occur, but water transfers are taxed and the revenue goes into a fund from which affected third-parties can be compensated. At the end of the water year, anyone damaged by a water transfer may file a claim for compensation. An impartial arbitrator evaluates any claims and uses the tax revenue to compensate victims. Because the water transfer is decoupled from third-party compensation, these institutions have two components: (1) a taxing mechanism to generate revenue for compensating third-parties, and (2) an arbitration mechanism through which victims can file claims for damages.

Taxing mechanism. In the two tax treatments, either a per-unit or a revenue tax is imposed on all transfers, and the revenue placed in third-party compensation fund. At the end of the water year, an arbitrator evaluates any third-party claims and fully compensates them for any damages. For such a compensation mechanism to be viable, it needs to guarantee that (a) third-parties are fully compensated, (b) water traders are not paying taxes in excess of damages, and (c) the fund will remain solvent over time. These three conditions yield the constraint that total (not marginal) tax revenue must exactly equal total damages in each year. The tax rate is set at the beginning of the water year by a regulator who has perfect information about all market participants. With this information, the regulator can estimate the damages that would occur in a competitive equilibrium. What he cannot predict, however, is how participants will actually trade. With perfect foresight, the regulator would set the tax rate such that revenues collected from water transfers exactly equaled the level of third-party damages. The fund balance at the end of each year would then be zero.[1] In reality, because estimated third-party damages and tax revenues may not exactly match actual damages and revenues, it is possible that at the end of the water year the compensation fund may run a surplus or a deficit, depending upon whether revenues or damages were greater. If there is any revenue remaining in the fund after all third-parties are compensated, the residual funds are carried over to the next water year, resulting in a lower tax rate in the next year. Similarly, if there is insufficient tax revenue to fully compensate all third-parties, the fund goes into a deficit and will make up for the shortfall by raising the tax rate in the subsequent year.

We consider two types of taxes: a per-unit tax (UnitTax) and a revenue or ad valorem tax (RevTax). Tax revenue from a per-unit tax is based on the total volume of water traded, whereas tax revenue from a revenue tax is based on the total value of the water traded. In these experiments, the water seller is responsible for collecting the tax.[2]

Arbitration mechanism. The second component is an arbitration scheme to render judgments on how the money collected from the tax is to be distributed. Those adversely affected by the transfer can file a claim for compensation to a neutral arbitrator. Clearly, in such an arbitration mechanism there are strong incentives for third-parties to over-estimate damages and file frivolous claims. It is incumbent upon the arbitrator to determine the true damages. In this research, we avoid this incentive problem by assuming a perfectly informed neutral arbitrator. This computerized robot arbitrator has perfect information on the value of water for all market participants, including third-parties. Using this information, the arbitrator can calculate the exact level of third-party damages and fully compensate victims. Although, in reality, this is obviously not the case, this assumption allows us to take out the role of the arbitrator and award exact compensation to third-parties. By taking out the vagaries of the arbitration process, we can focus solely on the ability of the tax scheme to account for actual damages.

Experimental procedures

This research focuses on three different market institutions described in the previous section. These are: (1) third-parties as Buyers in the water market (3PBuyer); (2) a per-unit tax imposed on all water trades (UnitTax); (3) a revenue tax imposed on all water trades (RevTax). Water is allocated using a computer-assisted uniform price sealed bid double auction. As a price mechanism, the market's distinguishing feature is that all accepted bids to buy are filled at a price less than or equal to the lowest accepted bid price of buyers—a price that just clears the market by making the total number of units sold equal to the number purchased. Similarly, all accepted offers to sell water are filled at a price greater than or equal to the highest accepted asking price of sellers. An appealing feature of this mechanism is that there is a uniform price for the water itself; any differences in the price at a particular location represent the conveyance costs, third-party impacts and transfer taxes associated with that site.

We present the results collected from eighteen computer-based experiments divided evenly across the three treatments. Participants for the experiments were recruited from the student population at the University of Massachusetts. The experiments utilized web-based water market software designed specifically for this research. Participants were required to commit to a pair of two-hour sessions. The first day was used for training. All participants read the online instructions and took part in several rounds of practice trading.[3] The parameters for the trainer were different from that used in the real data sessions, and none of the data collected on the training days was used for analysis. The second day was reserved for the experiments in which usable data were collected.

The software used for the experiments displayed the entire water network to each participant on his or her computer screen and showed information about the network. The network consisted of various buy nodes at which there was both consumptive and nonconsumptive demand for water, reservoir nodes from which water was sold, and canals or rivers that connected the nodes. Water conveyance was provided by computer robot that simply revealed its supply costs.[4] Subjects were active as buyers, sellers or third-parties. Each participant was randomly assigned a role that defined the location(s) at which he or she was active throughout the experiment.

All sellers received an exogenous inflow of water each period. Their induced supply schedule represented the per-unit costs of selling water. The costs were the lowest price for which the sellers could profitably sell their water. Sellers earned money by selling water at a price above these costs. Buyers submitted bids in each round based on an induced demand schedule. These values represented the benefit they received from consuming the water. Their bids represented the most they were willing to pay for a given amount of water delivered to their location, including the cost of the water, conveyance costs and transfer taxes. Buyers earned money by purchasing water at a price lower than the benefit they received from consumption. Non-consumptive users in the 3PBuyer experiments also submitted bids based on an induced demand schedule similar to that of buyers. However, the third-parties did not consume the water and received a benefit from the total amount of water consumed by buyers at their location regardless of whether they contributed its the provision. The induced values for all agents are in Tables 1a and 1b.

<<INSERT TABLES 1a and 1b>>

Each experiment consisted of 16 to 20 periods in which odd numbered periods were considered ‘wet’ water years (higher inflows and lower buyer values) and even numbered periods were considered ‘dry’ water years (reduced inflows and higher buyer values). All wet years were identical, as were the dry years. Each year, trading occurred in a spot market for one-year leases. Water could not be stored for future use. During the period, participants could submit location-specific bids and asks. Subjects could divide these submitted bids and asks into as many as five separate price-quantity steps. Each period lasted about 5 minutes and all participants were allowed to submit bids and asks as often as they wished. Only the last submission was used by the computer. The allocation mechanism in this paper adapts the model in Murphy, et al. 2000 to include the economic benefits of non-consumptive use. When each trading period ended, the central computer took the input data from all participants and solved the following network flow problem:

Maximize total surplus: $$-\sum_i c_i f_i + \sum_i b_i f_i \qquad (1)$$

subject to:

balance of flow: $$\sum_{i \in S_k} f_k = \sum_{i \in E_j} f_j \quad (\forall \text{ nodes } j); \qquad (2)$$

conveyance capacity: $$d_i \le f_i \le u_i \quad (\forall \text{ arcs } i) \qquad (3)$$

Each arc (i) in this formulation represents one bid or offer. If a buyer makes a multi-part bid, then each part is represented by separate, parallel arcs. Multi-part offers by sellers are represented similarly. Thus, each bid or offer is represented by the vector (s_i, e_i, d_i, u_i, c_i) with s_i being its starting node, e_i its end node, d_i the least permissible flow on that arc, u_i the greatest permissible flow on that arc (determined by the bid or offer quantity entered), and c_i the bid value or offer price per-unit of flow on that arc (bid values are treated as negative costs) and b_i is the third-party bid for flow along that arc. The flow on arc i is f_i, S_j is the set of arcs which begin at node j, and E_j is the set of arcs which end at node j. Note that constraint set (2) maintains the balance of flow at each node j. Intuitively, equation (2) describes the network and equates supply and demand. Constraint set (3) ensures that the flow on each conveyance arc does not exceed the stated lower or upper bounds. In the tax treatments, third-parties are not active, so $b_i = 0$, and the seller's bid includes both the seller's asking price and the tax.

Solving the linear programming problem above yields not only the optimal flows (and production and consumption patterns), but also the set of location-specific shadow prices for all nodes in the network. Since the shadow prices are marginal nodal values at which water is bought and sold, the difference in shadow prices at the start and end nodes of an arc yields the value of the marginal unit of flow on that arc which is the price associated with water conveyance. The software displays the results immediately following each period including profits and which bids or asks were accepted.

The laboratory water market was a simplified version of the California water network. Figure 1 contains an illustration of the laboratory water market. There were two main surface water sources: the Sacramento and San Joaquin Rivers. These flow into the Delta from which water flows to Southern California cities through the Central Valley Project and the State Water Project. In addition to consumption by Southern California cities, there were three agricultural centers that use the water: Sacramento Valley Agriculture, North San Joaquin Valley Agriculture, and South San Joaquin Valley Agriculture.

<<INSERT FIGURE 1>>

Each subject in the experiment may have played more than one role. The two upper consumption nodes, Buy-1 and Buy-2, each had three buyers active. Consumption nodes Buy-3 and Buy-4 each had a single buyer. There were three water sellers located at each of the two reservoirs. In addition to the water being traded between the buyers and sellers, third-party impacts occurred at the two regions represented by nodes Buy-1 and Buy-2.

Results

In this section, we use the same criteria as Murphy, et al. 2000 to evaluate market performance: efficiency, price stability, and distribution of surplus. After defining the terms, we use these criteria to evaluate the performance of the water market. Each buyer of water, *b*, located at node *j* has a resale value, or benefit, schedule $B_{bj}(Q_{bj})$. All buyers *b* at node *j* pay the same market price for delivered water, P_j', and each buyer *b* earns a profit of:

$$\Pi_{bj}' = B_{bj}(Q_{bj}') - P_j' \, Q_{bj}' , \qquad (4)$$

where Q_{bj}' is the equilibrium quantity of water delivered to buyer *b* at node *j*. Each seller of water, *s*, located at node *j*, has a cost schedule $C_{sj}(Q_{sj})$, and in equilibrium all sellers *s* at node *j* receive the same market price, P_j', and each seller *s* earns a profit of:

$$\Pi_{sj}' = P_j' \, Q_{sj}' - C_{sj}(Q_{sj}') . \qquad (5)$$

Similarly, each third-party, *p*, located at node *j*, has a benefit schedule that is a function of the aggregate consumption in the region $B_{pj}\left(\sum_b Q_{bj}\right)$. In the 3PBuyer sessions, the third-party may contribute to the provision of water at his location (but will receive benefits from aggregate consumption at his node regardless of third-party contributions). Each third-party's contribution, or subsidy, to the provision of water at his location is S'_j , and each third-party *p* at node *j* earns a profit of:

$$\Pi'_{pj} = B_{bj}\left(\sum_j Q'_{bj}\right) - S'_j \sum_j Q'_{bj} \ . \tag{6}$$

Conveyance along each arc was provided at a constant marginal cost. The price for the water itself is uniform throughout the network, and any location-specific differences in the price for delivered water reflect conveyance costs and third-party contributions. Aggregate earnings for all buyers, Π'_{Buy}, are the sum of the individual buyers' earnings: $\Pi'_{Buy} = \sum_b \sum_j \Pi'_{bj}$.

Aggregate seller earnings, Π'_{Sell}, and aggregate third-party earnings, Π'_{3P}, are defined similarly.

Note that the computer calculates the actual market prices and allocations based on the submitted bids and asks of each agent. We can also calculate the competitive equilibrium prices, allocations, and earnings for each subject by using the induced values as shown in Table 1a and 1b, and then applying equations (1) – (3). Because the perfectly competitive equilibrium (denoted with an asterisk *) maximizes the possible gains from trade, we use this as a baseline against which the realized market outcomes (denoted with a prime ′) can be compared. Efficiency measures the ability of the market to extract all of the potential gains from trade. It is the share of potential surplus realized by the market:

$$Efficiency = \frac{\Pi'_{Buy} + \Pi'_{Sell} + \Pi'_{3P}}{\Pi^*_{Buy} + \Pi^*_{Sell} + \Pi^*_{3P}} \in [0,100\%]. \quad (7)$$

The competitive equilibrium results in an allocation that maximizes the total possible surplus for a given institution and environment, thus, a perfectly competitive market will be 100 per cent efficient.

Result 1. The revenue tax treatment produced the most efficient outcomes. The evidence is mixed about whether active third-party participation and a unit tax yield comparable levels of efficiency.

In a perfect world in which the revenue collected exactly equaled the damages compensated, the tax rate in each period would be the same. However, if a surplus or deficit in the compensation fund exists, it will be carried over into the following year. This implies that the tax rate in each period of the experiment may differ to account for this. Therefore, we define the competitive equilibrium surplus as the level of total surplus that would occur in a competitive market given the actual tax rate for that period. Table 2 presents the mean and median efficiency for each of the three treatments. We present the summary statistics for all periods (excluding periods 1 and 2),[5] and again after dropping periods 1 through 10 to get a sense for how these markets converge in the later rounds. By all measures, the RevTax treatment consistently yielded the highest efficiency. Mean and median efficiency in all periods (92 and 93 per cent, respectively) was greater than either of the other two treatments. Moreover, in nearly three-quarters of the RevTax periods, efficiency exceeded 90 per cent, whereas less than one-third of the periods in 3Buyer and about 40 per cent of the periods in UnitTax exceeded this benchmark. For all three treatments, performance increased in the later rounds.

<<INSERT TABLE 2>>

The 3PBuyer treatment has the lowest median efficiency in all periods, as well as just the later rounds. 3PBuyer also has the lowest mean efficiency in the later rounds and the lowest share of periods with efficiency above 90 per cent. We used both Wilcoxon rank sum and median two-sample tests to determine whether these differences in efficiency across treatments were statistically significant. The results of these pairwise comparisons strongly reject the null hypothesis that the efficiency in the RevTax equals that of either UnitTax or 3PBuyer ($p = 0.00$). Comparison of efficiency for UnitTax vs. 3PBuyer yields a similar conclusion.

In addition to the non-parametric tests, we also used a random effects model to estimate efficiency while controlling for group effects. Table 3 reports the results of a random effects model in which efficiency is a function of treatment, type of water year (wet or dry), and a dummy variable that equals one for periods 3-10. The 18 individual sessions are the random effects. The omitted dummy variables are for UnitTax and wet years. After controlling for individual group effects, RevTax has a 6.87 percentage point higher efficiency than the UnitTax treatment. The coefficient for 3PBuyer is not statistically significant, suggesting that there is no difference in efficiency between the UnitTax and 3PBuyer treatments. The coefficient on the dummy variable for Periods 3 to 10 is negative and significant, indicating that efficiency increases roughly 5 percentage points in the later rounds of an experiment.[6] There is no significant difference in efficiency between wet and dry years.

<<INSERT TABLE 3>>

Result 2. Although 3PBuyer has lower average market efficiency than RevTax, it has the highest level of realized surplus.

The second column of Table 4 shows that the competitive equilibrium surplus in 3PBuyer treatment (7626) is greater than the competitive equilibrium surplus of the two tax treatments (6704 for UnitTax and 6872 for RevTax).[7, 8] The tax rates in the UnitTax and RevTax treatments are not, and cannot be, efficient because the tax rates are set to equate total (not marginal) expected damages and total expected revenue, and the tax rates are not spatially discriminative.[9] Since the 3PBuyer treatment fully accounts for the marginal costs and benefits of third-party impacts, but the tax treatments do not, the level of total surplus in the perfectly competitive equilibrium for 3PBuyer is necessarily greater than that in the tax treatments.

<<INSERT TABLE 4>>

With our parameters, the efficiency loss in the tax treatments is around 10 per cent. This 10 per cent efficiency loss has important implications in evaluating the relative merits of each institution. Table 4 shows that the average level of realized surplus in the 3PBuyer treatment was greater than that of either tax treatment (6603, as compared to 6261 and 5788 for RevTax and UnitTax, respectively). Essentially, 3PBuyer offers a smaller piece of a bigger pie. What can we say about the relative merits of the different institutions if 3PBuyer has the lowest efficiency, but the highest level of available surplus? In general, we would expect that 3PBuyer will always have the highest level of potential surplus, but will be less efficient at extracting this surplus (from Result 1). However, the relationship of the levels of realized surplus from trading in the three institutions is an empirical question that will depend on the magnitude of the efficiency losses due to the tax.

Result 3. In the two tax treatments, observed prices are slightly higher than the competitive equilibrium, but prices adjust well to changes in market conditions and price volatility is low.

In addition to market efficiency, we are also interested in how the observed market price compares with the competitive equilibrium price. This evaluation has three dimensions: (1) Does the average market price equal the competitive equilibrium price? (2) Is the observed market price stable with low volatility? (3) Does the observed market price react quickly to changing circumstances? In the two tax treatments, the observed market price performs reasonable well on all three counts.

In this analysis, we arbitrarily chose the price at node Buy-1 to serve as the "base" price of water. In all three institutions, the price of the water itself is uniform across all locations in the network. Any differences in prices at a location are due to conveyance costs and, in the 3PBuyer sessions, to third-party contributions. Table 5 reports the competitive equilibrium and market prices of water at Buy-1 for all treatments in both wet and dry years. For the two tax treatments, the mean price is slightly higher than the competitive equilibrium, and, although the difference is generally small, it is statistically significant.[10] Because of this, the actual distribution of surplus tends to favor the sellers. Moreover, the market price tracks the competitive equilibrium in both wet and dry years, indicating that the market is responding well to changes in market conditions. The mean price in the RevTax treatment was the closest to the competitive equilibrium, which is consistent with the higher levels of efficiency observed in this institution.

<<INSERT TABLE 5>>

As a measure of price volatility within an experiment, we use the mean absolute deviation (MAD) of prices, measured in per cent deviations from the mean price for each group (we use the mean for each group, rather than treatment, to control for group effects). All three treatments exhibited low volatility. RevTax had the most stable prices, with a MAD of 1.4 per cent. This indicates that, on average, the difference in prices over time for a particular group in the RevTax treatment was quite small. The MAD for UnitTax was 2.2 per cent, and 3PBuyer was 3.3 per cent.

Result 4. In the 3PBuyer treatment, third-party contributions are consistent with some demand under-revelation.

In the competitive equilibrium, third-parties active at nodes Buy-1 and Buy-2 contribute money to increase water consumption in their region. However, given that these third-parties receive a benefit for all water flowing into their region, regardless of their contributions, there is clearly a strong incentive to free ride and contribute nothing. Table 6 provides summary statistics for the ratio of actual third-party contributions to competitive equilibrium contributions. On average, the third-party contribution at Buy-1 is 45 per cent of the competitive equilibrium price, and 69 per cent at Buy-2. These results are consistent with those reported by Murphy, et al. 2004 for the same institution. With the exception of Buy-2 in wet years, contributions are clearly below the competitive equilibrium, however there is substantial variation in the extent of the free riding across groups. Table 7 presents the results of a random effects model using the per cent of the competitive equilibrium third-party contribution as the dependent variable and the group as the random effect. There is a significant difference in contributions between nodes and between water year types.[11] Consistent with results in typical public goods experiments, contributions decline by 12 percentage points in the later rounds. On average, third-parties earned more than double what they would in the competitive equilibrium, but there was significant variation across individuals (mean 216 per cent, standard deviation 131 per cent, median 165 per cent). This free riding resulted in about a 25 per cent reduction in the total quantity of water traded, and a transfer of surplus from the communities with the third-parties to those without third-party impacts. Given that economic activity is dependent on the quantity of water flowing into the region, agricultural communities could face adverse long-term consequences if free riding persists.

<<INSERT TABLE 6>>, <<INSERT TABLE 7>>

Result 5. The tax schemes could have equity implications if traders are not the same from year to year.

The tax rate is calculated before the market opens and assumes perfectly competitive outcomes. If the actual outcomes do not equal the competitive equilibrium, the tax rate is imperfect in the sense that total revenue collected does not equal total damages. If the tax were perfect, the tax rate would be zero in all wet years, but we consistently observed tax rates approaching $10 per-unit or 14 per cent of revenue. Although our results suggest that the mechanism is successful in its intent to compensate third-parties, the results also point to important equity implications. Because no damages occur in the wet years, a non-zero tax rate in these years means that any wet year traders are paying for damages that occurred in previous years. Essentially, part of the burden of the tax is passed on from dry year traders to wet year market participants. Moreover, this shift in the tax burden over time could affect the market entry decisions for some participants.

One last comment on the tax rates regards the potential bankrupting the compensation fund. This market environment was designed so that dry years (when damages are high) alternate with wet years. We found that increasing the tax in the wet years was often sufficient to make up for any shortcomings in the dry years. However, a prolonged drought could keep the fund balance in a deficit for a number of consecutive years. Because a deficit causes the tax rate to increase in the following year, the tax rate could potentially rise to a point where it makes the water transfers prohibitively expensive. One possible means of reducing the likelihood of this occurring is to spread the surplus or deficit across multiple years.

Conclusion

California's drought water banks clearly demonstrated the economic benefits that voluntary short-term water transfers can provide. However, the water banks relied upon predetermined "prices" set by the California Department of Water Resources, and these fixed "prices" did not adjust with changes in supply or demand. The use of computer-coordinated 'smart' markets for water offer California the potential to increase the efficiency of short-term water transfers while protecting environmental, social and economic interests. This paper extends that research by testing whether and how these computer-coordinated water markets can incorporate third-party values into the water allocation mechanism.

This research used laboratory experiments and a computer-coordinated market to analyse three alternatives designed to protect third-parties. The options tested range from (1) a free-market environment in which third-parties are allowed to directly participate in the market and bid for water; (2) a pair of mechanisms which allow all transfers to occur but these trades are taxed to finance third-party compensation. The RevTax experiments produced the most efficient results. The UnitTax experiments exhibited some volatility in early periods but by later periods reached average efficiencies exceeding 90 per cent. The 3PBuyer experiments, on the other hand, rarely reached average efficiencies of 90 per cent in any given period. Further analysis showed that some of the losses in the 3PBuyer treatment can be attributed to partial free riding by the third-parties.

However, the lower efficiencies described here do not alone imply that any market mechanism is more or less preferred than another. As pointed out in Result 2, this is because the level of potential surplus varies across institutions. Taking this difference of available surplus into consideration, efficiency can be thought of in a second way: compare average realized surplus with competitive equilibrium surplus for the institution that yields the highest possible level of total surplus. If an institution reaches 100 per cent efficiency by this definition, then it has realized the maximum amount of total surplus for any institution. This distinction is particularly important when considering a command and control type mechanism to regulate water transfers. These regulated markets quickly reach high efficiencies based on the first definition and show little variation. However, because of the regulatory constraints, the amount of available surplus is lower so, although they perform well given the constraints, there may be other more flexible institutions that can increase overall welfare.

Our results show that although the 3PBuyer institution had the potential for high efficiencies by both definitions, free riding and strategic behavior eroded most of the potential gains. The RevTax experiments were able to realize high levels of efficiency by the first definition and still realize levels of surplus comparable to the 3PBuyer market. Although key issues such as the distribution of surplus and equity need further attention, a tax on water transfers may be appealing because it offers high levels of efficiency and market stability and is more flexible than fixed limits on water transfers. In the long-run, however, continued third-party compensation minimizes any incentives to engage in some other, more productive economic behavior. A policy that includes third-party compensation for long-term transfers might benefit from a sunset provision that phases this compensation out over time.

Endnotes

[1] The tax rate is set at the start of the water year and remains fixed until the following year.

[2] Although the statutory incidence of the tax falls on sellers, the economic incidence will be shared by both buyers and sellers.

[3] The instructions are available at http://www.umass.edu/expecon/instructions/water/. The third-party buyer and tax instructions are identical, except for changes that reflect the differences that are unique to the treatments. The instructions are not neutral in the sense that subjects were aware that this was a water market experiment. Given the sensitive nature of water markets, this could introduce some biases. However, we feel it is unlikely since students at the University of Massachusetts are generally unaware of these issues.

[4] Subjects were aware of this.

[5] Unless otherwise noted, we drop the results from periods 1 and 2 to minimize learning and price discovery effects. This has no effect on the qualitative conclusions.

[6] We also modeled learning using Period and $Period^2$; this yields the same conclusions.

[7] The competitive equilibrium surplus of the UnitTax and RevTax treatments differs slightly due to the discrete nature of the supply and demand step functions.

[8] Table 4 reports the efficiency comparison only for dry years. A comparison for wet years yields similar results.

[9] Efficiency would require that consumption be subsidized at locations with third-party impacts. The subsidy rate would differ by location based on marginal third-party impacts. The subsidy would yield prices that are identical to the competitive equilibrium prices in the 3PBuyer treatment.

[10] It is possible that these small deviations are at least partially to the discrete, step-wise nature of the supply and demand functions.

[11] The reason for the difference in free-riding across nodes is unclear, however we suspect that much of it may be attributable to the individual in the role of 3rd party. With this model, there are substantial group effects. For example, the coefficient for session 3PBuyer01 is –31.5 and is significant at the 1% level. On the other hand, the coefficient for session 3PBuyer06 is 33.4 and is also highly significant. This suggests that, although some free riding was consistently observed, the magnitude of the free riding depends upon the individuals. Although there is a difference in the magnitude of the effect between nodes, the qualitative conclusions about free-riding are the same. The key policy implications here are not the precise quantitative estimates, but rather the qualitative conclusions that can be drawn from the results.

References

Anderson, T., and P. Snyder (1997), Water Markets: Priming the Invisible Pump, Washington, DC: Cato Institute.

California Department of Water Resources (2004), California Water Plan - Update 2004, Advisory Committee Review Draft, Vol. 2, Sacramento, CA: California Department of Water Resources, June 7.

Dinar, A., R. E. Howitt, S. J. Rassenti, and V. L. Smith (1998), 'Development of Water Markets Using Experimental Economics', in K. W. Easter, M. Rosegrant, and A. Dinar (eds.), Markets for Water Potential and Performance, Boston: Kluwer Academic Publishers.

Gray, B. (1996), Maintaining Momentum on California Water Issues: A Model Water Transfer Act for California, Sacramento, CA.

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.

Hanak, E. (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.

Huffman, J. (1983), 'Instream Water Use: Public and Private Alternatives', in T. Anderson (ed.), Water Rights: Scarce Resource Allocation, Bureaucracy, and the Environment, San Francisco: Pacific Institute for Public Policy Research, pp. 249-282.

Landry, C. (1998), Saving Our Streams Through Water Markets: A Practical Guide, Bozeman, MT: Political Economy Research Center.

McCabe, K. A., S. J. Rassenti, and V. L. Smith (1989), 'Designing 'Smart' Computer-Assisted Markets: An Experimental Auction for Gas Networks', European Journal of Political Economy, 5, 259-283.

McCabe, K. A., S. J. Rassenti, and V. L. Smith (1991), 'Smart Computer-Assisted Markets', Science, 254, 534-538.

Murphy, J. J., A. Dinar, R. E. Howitt, S. J. Rassenti, and V. L. Smith (2000), 'The Design of 'Smart' Water Market Institutions Using Laboratory Experiments', Environmental and Resource Economics, 17 (4), 375-394.

Murphy, J. J., A. Dinar, R. E. Howitt, S. J. Rassenti, V. L. Smith, and M. Weinberg (2004), Incorporating Instream Flow Values into a Water Market, University of Massachusetts-Amherst, Department of Resource Economics Working Paper 2004-08, Amherst, MA.

Vogel, N. (2002), 'Water Exchanges Help State Through Dry Years', Los Angeles Times, April 4, Metro, part 2 p. 1.

Water Transfer Workgroup (2002), Water Transfer Issues in California, Final Report to the California State Water Resources Control Board, Sacramento, CA: California State Water Resources Control Board, June.

Weber, M. L. (2001), 'Markets for Water Rights under Environmental Constraints', Journal of Environmental Economics and Management, 42 (1), 53-64.

Table 1a. Induced values for wet years

Role	Location		Step1	Step2	Step3	Step4	Step5	Inflow
Buyer 1	Buy-1	Price	75	67	59	51	37	
		Quantity	8	8	6	6	16	
Buyer 2	Buy-1	Price	73	65	57	42	36	
		Quantity	8	8	6	7	16	
Buyer 3	Buy-1	Price	71	63	55	43	38	
		Quantity	8	8	6	11	14	
Buyer 4	Buy-2	Price	53	45	37	27	21	
		Quantity	8	8	7	6	16	
Buyer 5	Buy-2	Price	55	47	39	29	20	
		Quantity	8	8	6	10	16	
Buyer 6	Buy-2	Price	57	49	41	31	19	
		Quantity	8	8	6	7	16	
Buyer 7	Buy-3	Price	95	87	79	67	61	
		Quantity	4	4	4	8	6	
Buyer 8	Buy-4	Price	119	111	103	91	86	
		Quantity	4	4	4	8	6	
Seller 1	Res-1	Price	36	40	43	49	60	
		Quantity	8	8	10	10	20	56
Seller 2	Res-1	Price	36	40	47	51	58	
		Quantity	8	8	10	10	20	56
Seller 3	Res-1	Price	36	40	46	53	56	
		Quantity	8	8	10	8	20	54
Seller 4	Res-2	Price	19	23	28	33	42	
		Quantity	8	8	10	10	20	56
Seller 5	Res-2	Price	19	23	27	35	40	
		Quantity	8	8	10	8	20	54
Seller 6	Res-2	Price	19	23	31	37	38	
		Quantity	8	8	10	8	20	54
3rd Party 1	Buy-1	Price	24	21	16	9	5	
		Quantity	46	16	20	20	30	
3rd Party 2	Buy-2	Price	22	19	12	7	3	
		Quantity	46	16	20	20	30	

Table 1b. Induced values for dry years

Role	Location		Step1	Step2	Step3	Step4	Step5	Inflow
Buyer 1	Buy-1	Price	140	109	105	94	90	
		Quantity	4	4	4	8	6	
Buyer 2	Buy-1	Price	128	120	106	101	68	
		Quantity	4	4	4	4	6	
Buyer 3	Buy-1	Price	122	114	81	74	58	
		Quantity	4	4	4	8	6	
Buyer 4	Buy-2	Price	107	109	93	77	48	
		Quantity	4	4	4	8	6	
Buyer 5	Buy-2	Price	103	95	79	72	64	
		Quantity	4	4	5	8	6	
Buyer 6	Buy-2	Price	115	101	89	70	51	
		Quantity	4	4	4	8	6	
Buyer 7	Buy-3	Price	170	164	144	133	112	
		Quantity	8	8	4	8	6	
Buyer 8	Buy-4	Price	196	188	170	158	146	
		Quantity	8	8	4	8	6	
Seller 1	Res-1	Price	73	77	97	100	125	
		Quantity	6	4	4	4	20	38
Seller 2	Res-1	Price	67	79	91	98	140	
		Quantity	7	4	4	4	20	39
Seller 3	Res-1	Price	65	85	89	105	115	
		Quantity	7	4	4	6	6	27
Seller 4	Res-2	Price	48	52	64	76	97	
		Quantity	6	4	4	4	6	24
Seller 5	Res-2	Price	40	58	70	80	107	
		Quantity	7	4	4	4	20	39
Seller 6	Res-2	Price	46	60	72	87	112	
		Quantity	7	4	4	10	20	45
3rd Party 1	Buy-1	Price	31	29	15	10	8	
		Quantity	20	20	7	7	6	
3rd Party 2	Buy-2	Price	29	26	13	9	7	
		Quantity	20	20	7	7	6	

Table 2. Summary statistics: Efficiency for each treatment

	All Periods (excl. Per 1-2)				
Treatment	**N**	**N > 90%**	**Mean**	**Std Dev**	**Median**
3PBuyer	88	26 (30%)	86.0	7.8	86.4
RevTax	108	77 (71%)	92.1	6.4	93.3
UnitTax	100	39 (39%)	85.1	10.4	88.3
	Only Periods ≥ 10				
3PBuyer	40	15 (38%)	87.8	5.8	87.4
RevTax	60	48 (80%)	93.6	4.9	94.3
UnitTax	52	26 (50%)	89.3	5.7	90.1

Table 3. Market efficiency – Estimates from a random effects model

Variable	Coefficient	Standard Error
Intercept	87.54 ***	2.25
3PBuyer	1.26	3.10
RevTax	6.87 **	3.08
Dry Year	-0.02	0.76
Periods 3 to 10	–5.08 ***	0.77

Dependent variable: Efficiency in each period (excludes periods 1-2). Number of observations: 296. Model significance (Pr>Chi-square): <.0001. *** = significant at 1%, ** = significant at 5%.

Table 4: Efficiency comparison for dry years[a]

Treatment	Competitive Equilibrium Surplus	Average Realized Surplus	Average Efficiency[b]	Avg. Efficiency Relative to Maximum Possible Surplus[c]
3PBuyer	7626	6603	87%	87%
RevTax	6872	6261	91%	82%
UnitTax	6704	5788	86%	76%

[a] Excludes periods 1 – 2.

[b] Average realized surplus for each treatment divided by competitive equilibrium surplus for that treatment.

[c] Average realized surplus for each treatment divided by competitive equilibrium surplus for 3PBuyer treatment (7626).

Table 5. Summary statistics: Price at Buy-1 for each treatment

	Wet Years			Dry Years		
Treatment	**Comp. Equil. Price**	**Mean Price**	**Std. Dev.**	**Comp. Equil. Price**	**Mean Price**	**Std. Dev.**
3PBuyer	54	48.1	2.4	121	99.9	7.9
RevTax	51	53.8	1.5	114	114.6	2.4
UnitTax	51	57.1	3.3	116	118.7	4.5

Table 6. Actual third-party contributions as a per cent of the competitive equilibrium contribution

Node	Mean	Std Dev	Median
Buy-1	45.5%	33.9%	45.5%
Buy-2	68.7%	48.0%	62.5%

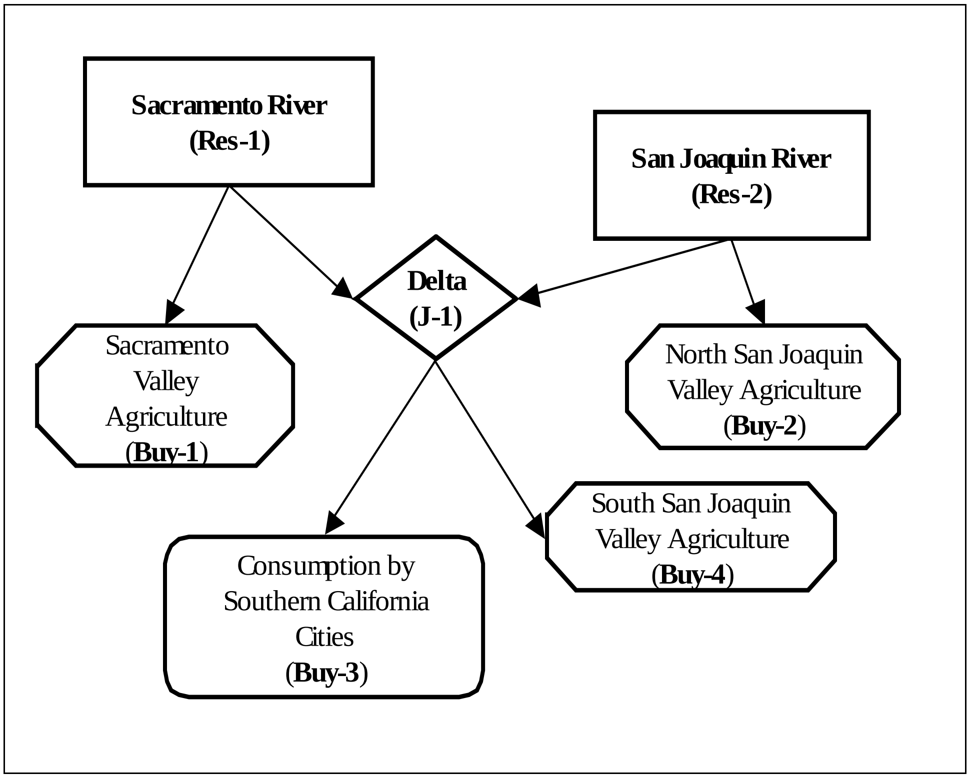
Table 7. Per cent of competitive equilibrium third-party contributions – Estimates from a random effects model

Variable	Coefficient	Standard Error
Intercept	78.7 ***	11.4
Node Buy-1	-23.7 ***	4.6
Dry Year	-31.5 ***	4.6
Periods 3 to 10	12.0 ***	4.6

Dependent variable: Per cent of competitive equilibrium contributions by third-party in each period (excludes periods 1-2). For purposes of brevity, the group-specific random effects are not included in this table. Number of observations: 176. Model significance (Pr>Chi-square): <.0001.

*** = significant at 1%.

Figure 1: Diagram of water flow in the laboratory water network



The labels in parentheses correspond to the location names used in the experiment.

List of symbols used in manuscript

$\forall$: p 11, equations 2,3

$\leq$: p 11, equation 3

$\in$: p 11, equations 2,3; p 14 equation 7

$\sum$: p. 11, equations 1, 2; p. 13 in text; p. 14 equation 6 and in text