Valuing Options in Water Markets: A Laboratory Investigation

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Abstract. Risk and reliability dominate water supply discussions in the arid western United States in light of increasing demand and finite, weather-dependant supply. Thus water agencies increasingly turn to contractual mechanisms such as dry-year options to manage supply risk in advance of need. Although a few water agencies across the West have implemented dry-year options, sufficient data for conventional econometric analysis do not yet exist. We thus utilize experimental economics to analyze the effect of annual dry-year options on water markets. We consider how market structure (competitive versus monopsony power) and option contract availability affect water price and allocation within a market and find that realized gains from trade are on average higher when options can be traded, by 46% in competitive markets and by 63% in dominant buyer markets. Important for the political feasibility of such markets, we also find that gains from trade, once an options market is available, are much more evenly distributed between the single buyer and the many sellers in the case of monopsony. (JEL D23, L22, Q25)

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Introduction

Population growth and environmental demands on existing water supplies will continue to increase in California and elsewhere in the coming years. To address this worsening scarcity problem, many regions have developed water markets to facilitate transfer of water from existing rights holders to buyers with higher-value uses. In the future, even more flexible arrangements for trading water, such as option contracts and water banks, could further increase allocative efficiency. Under a typical option agreement, a water agency pays an option premium in the fall for the right to purchase water from a seller should the water year turn out to be dry. If the water year turns out to be wet so that the holder of the option has sufficient supplies, the water is neither transferred nor paid for, but the buyer still pays the seller the option premium. The option value represents the value to the buyer of sharing the risk of water supply uncertainty with the seller (Howitt 1998).

We use experimental economics to elicit information on efficiency gains and distributional effects from water options. Specifically, we utilize the controlled laboratory environment to isolate the effects of market concentration and contract availability on the efficiency of markets, in a way that is not possible with the minimal data on existing water options contracts. The laboratory permits observation of trader behavior in the presence of input supply uncertainty, where the uncertainty is driven by stochastic realizations of a water input. The laboratory also permits study of buyer concentration on market outcomes, a relevant topic since existing bilateral options in California are primarily purchased by a single entity, the Metropolitan Water District of Southern

California (MWD).[1] Furthermore, since subjects in this study were not informed that the good they were trading was water, the results are generalizable to other natural resources used as inputs into production processes.

California Water Markets

In California, matching supply with demand is complicated by the fact that most precipitation falls in the northern part of the state while population centers and high-value agriculture lie in the more arid central and southern parts of the state. Also, precipitation varies significantly from year to year.[2] Increased use of flexible contract instruments such as options could assist more conventional market transfers in allocating water. The California Department of Water Resources (CDWR) has sponsored option contracts among water agencies in the past (Jercich 1997); in other instances, water agencies have initiated such deals themselves (San Diego County Water Agency; Metropolitan Water District of Southern California).

Regardless of whether future option agreements take place under the sponsorship of a state agency or bilaterally, increased water option activity in the future is desirable on efficiency grounds, as options have several important advantages over permanent transfers or short-term leases. For instance, options often require less regulatory oversight than permanent transfers, as impacts to the environment and third parties are smaller if water is only transferred during dry years when it has the highest scarcity value (Hanak 2001). Options are also more likely to be acceptable to exporting communities concerned about loss of long-term economic viability than permanent transfers or leases that occur

[1] MWD is a wholesale water agency whose 26 member water agencies collectively serve approximately 17 million people in the Los Angeles and San Diego areas.

[2] Unimpaired runoff on the Sacramento and San Joaquin Rivers was less than 80% or greater than 120% of average in 40 and 34, respectively, of the 100 years between 1908 and 2007 (California Department of Water Resources 2007).

every year. Options also offer several advantages over short-term leases, chief among them the fact that options may help resolve in advance different preferences of buyers and sellers regarding the timing and manner of transfer. Options also offer several advantages over short-term leases, chief among them the fact that options may help resolve in advance different buyer and seller preferences regarding the timing and manner of transfer. For example, a rice grower may be persuaded by an option premium to postpone his planting decision until after a certain date (namely, the exercise date of the option contract) if the option premium he receives in the fall is sufficient to cover the added costs he incurs from waiting (Howitt, Moore and Smith 1992; Dixon, Moore and Schechter 1993; Coppock and Kreith 1992).

Analysis of existing option trading activity in California would provide valuable information to policymakers regarding gains from trade associated with implementation of option agreements, who would benefit from them, and how their existence might change trading behavior in the underlying water market. However, although use of option agreements is growing, their number is still small enough that conventional quantitative analysis of existing data is difficult. Even during dry years, markets are still relatively thin; trades that occur through market-based prices rather than administratively set prices are even rarer. Furthermore, because market agents are often reluctant to reveal transaction prices, there are very few observations of water trades, let alone water options, to provide a basis for econometric estimation. Two recent studies have analyzed water options (Watters 1995; Villinski 2003), but neither study was able to perform formal tests of efficiency, for lack of sufficient data.

We thus turn to experiments to address the question of whether sufficient gains from trade might be generated from more widespread use of annual dry-year options. Experiments have been used to test alternative institutional designs and to facilitate the design of workable policies before they are needed. Laboratory experiments are politically and financially less expensive and yield faster results than immediate implementation of a new market institution in the real world. Experiments allow policymakers to explore the viability of new market institutions under controlled experimental conditions, providing them with the opportunity to mitigate unforeseen problems before costly or irreversible decisions have been made (Murphy et al. 2000).

Experiments have been used to test a number of issues related specifically to water. One such area of active research has been to explore the potential for water market institutions to reduce water salinity. For example, Ward et al. (2007) test different auction mechanisms and the use of communication among farmers for a proposed recharge cap and trade market in the Bet Bet catchment in Victoria, Australia.[3]

Murphy et al. (2000) are the first to apply experimental economics specifically to water markets. They focus on conveyance, an issue central to water allocation in arid regions, by evaluating the implications of two different property right structures for conveyance capacity. Their results suggest that cotenancy on conveyance facilities increases efficiency and surplus and minimizes price volatility, relative to monopoly control. Murphy et al. (2003) examine alternative water market institutions for protecting third parties from economic harm resulting from water exports. The issue is particularly relevant in the water market setting because of the powerful political role third parties

[3] Tisdell, Ward and Cason (2004) and Duke, Gangadharan and Cason (2007) also conduct cap and trade market experiments in Australia, this time as a way to mitigate water quality issues related to salinity.

often play in the regulatory approval process. Murphy et al. (2007) compare three institutions for incorporating environmental instream flows into water markets. These papers test the use of incentive-based market solutions to address common problems in water markets and provide a springboard for discussion among policymakers of the relative merits of different solutions to common problems in water markets.

Garrido (2007) tests two elements of recent regulations authorizing water markets in Spain, namely the effects of banking and of proposed seniority rules on market efficiency. He finds that relaxing a restriction that junior rights holders are not allowed to purchase water from senior users increases senior rights holders' welfare without decreasing junior users' welfare. He also demonstrates that allowing users to bank water from one season to the next without losing rights to the water increases stock levels and reduces market price instability.[4]

In California, where active water markets already exist, the issue is no longer whether water markets would improve efficiency, but rather what type of trading would improve efficiency the most. We thus explore the relative efficiency of different market environments. The elements of interest are the effects of market power and contract availability on market efficiency: What is the effect of annual water options on the California wholesale water market under alternative market structure assumptions?

[4] The experimental literature on trading in option markets is rather thin, and its major focus is on how such markets aggregate information that is distributed asymmetrically among traders. For example, Kluger and Wyatt (1995) find that adding an options market to an asset market with asymmetrically informed agents increases the speed of information dispersion in the market and therefore efficiency, similar to results for future markets in the first asset market experiment (Forsythe et al., 1982). Abbink and Rockenbach (2006) observe that students perform better in an option pricing decision (without markets) than professional traders. For overviews of the experimental asset market literature, see Sunder (1995, 2007).

We are also interested in the distribution of gains from trade. Water allocation across the state has always been a contentious issue in California. Proponents of more flexible market mechanisms must overcome political hurdles. An efficiency-enhancing mechanism might not be implemented if the additional gains from trade were distributed more unevenly, an observation that is particularly apt in light of the monopsonic water market structure in the state.

Experimental Design

Subjects participated in computerized markets with four sellers and either one or four buyers. Each subject was assigned a role as buyer or seller, which reflects real-world conditions in California: Purchasers of annual water options in California are likely to be high-value agricultural and urban water agencies, and sellers are likely to be irrigation districts whose farmers can to some extent fallow low-value crops just before planting would have occurred. Within the experiment, buyers had value functions parameterized to mimic the incentives of urban and high-value agricultural water agencies that are willing to purchase water if the price is sufficiently low. Sellers had cost functions parameterized to mimic the incentives of low-value agricultural water agencies that are willing to sell if the price is sufficiently high. Sellers may consequently choose to lease out water in dry years when its market value is high and to retain the water as an agricultural input in wet and normal years.

Recall that the most notable feature of water supply in the western United States and California in particular is temporal and spatial supply variability. This experiment captures temporal fluctuations by varying the initial endowment of water subjects receive at the start of each period. Subjects' initial endowment of water has a uniform distribution reflecting three states of nature: dry, normal and wet.[5] Option value and usage may vary by location depending on hydrologic conditions, storage reserves, and physical and financial constraints on conveyance. We abstract from this spatial aspect of water trading to focus on the dynamic effect of option availability on water markets, and how the impact of option availability might vary within competitive versus dominant buyer markets.

We conducted experiments during the 2006-07 academic year. Subjects were drawn from the undergraduate student population at the University of California, Davis and at California State University Sacramento. In total, 365 subjects participated in the experiment, in 58 markets of five to eight subjects each. Each session lasted approximately two hours, and subjects earned approximately $30 on average. Experimental sessions were conducted using the software program Z-Tree (Fischbacher 2007).

Buyers and sellers traded water through a non-uniform price double auction according to the heterogeneous value functions assigned to them at the start of the session.[6] Subjects participated in one of four treatments, which varied by market concentration (competitive versus monopsony) and market institution (short-term contracts alone versus short-term contracts and option contracts). Subjects in all treatments first traded the generic good ("coupons") under conditions of certainty for eight periods, during Part 1 of the session. Each period, subjects learned the size of their

[5] CDWR classifies water years as dry, critically dry, above normal, below normal, or wet using two indices, the Sacramento Valley Water Year Index and the San Joaquin Valley Water Year Index, both of which incorporate current and previous year's water conditions (California Department of Water Resources 2007).
[6] We used neutral language in the experiment. The subjects were told that they were trading a generic production input rather than "water" and that the market state could be A, B or C rather than dry, normal or wet.

initial endowment of the good for that period before trading commenced. The initial endowment of the input good varied from period to period depending on the state of nature. In Part 1, subjects were informed at the start of each period whether the market was in state A, B, or C, which corresponded to varied endowments that differed by coupon size.[7]

Subjects were randomly assigned to be buyers and sellers. Sellers could either use their initial endowment of the generic good as an input into a production process, for which they received profits according to an increasing marginal cost function, or they could sell some or all of their initial endowment to buyers through the auction. Buyers received profits according to a decreasing marginal benefit function and could supplement their initial endowment of the good by purchasing additional units through the auction. In each period, the good was automatically used as an input into the production of a final good. Participants were compensated according to their net revenues from buying and selling the generic good in the auction and from profits from the sale of the final good. The value and cost functions of buyers and sellers were parameterized such that positive gains from trade existed in each state of nature.

After trading the generic good under conditions of certainty for the eight periods of Part 1, subjects began Part 2, in which they traded for 14 periods under conditions of uncertainty. At the start of each period in Part 2, subjects traded without knowing whether their initial endowment of the generic good consisted of four, six or eight

[7] Subjects were not permitted to store water from one period to the next. If the experiment allowed for banking, the effects of supply risk on equilibrium price and quantity would diminish, just as the presence of option contracts is shown here to diminish the effect of supply risk on equilibrium price and quantity. This is because option contracts and banking are to some extent substitutes for one another. Option agreements allow agencies to purchase protection from water supply risk in the marketplace; banking and reservoir storage minimize excess demand for water in the first place.

coupons. At the conclusion of each period, they learned the realized state of nature and their initial endowment of the traded good and what their profits from trade were. Subjects were informed that each of the three states of nature could occur with equal probability and that each period's state was independent of the previous period's state.[8]

The first treatment (C1) was a competitive market structure with four buyers and four sellers. The second treatment (DB1) was a dominant buyer market structure with one buyer and four sellers. The motivation for this treatment is that MWD has been the primary purchaser of option agreements in California. A dominant buyer's initial endowment of the generic good was as large as those of a all four competitive buyers in the C1 markets.

In the third and fourth treatments (C2 and DB2), subjects could also buy and sell options on the generic good, through a second non-uniform price double auction taking place concurrently with the auction for the generic good itself. Buying an option allowed the buyer to purchase an additional unit of the generic good after the state of nature was revealed at the conclusion of auction trading, if the buyer elected to do so. If a buyer elected to exercise an option, the seller from whom she had purchased the option consequently had one unit of the generic good subtracted from his supply and received a fixed payment (strike price) for the sold unit of the good.

Table 1 indicates the number of market observations contained within each treatment cell. Note that observations within each treatment cell use one of two sets of supply and demand functions. Within Set A, the supply and demand functions from which buyer and seller marginal benefit and cost functions are drawn are symmetric.

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[8] The order of the states of nature was determined randomly for the very first session and then, for the sake of comparison and unbeknownst to the subjects, kept the same for the remaining sessions.

Within Set B, the demand function is more inelastic than the supply function. This asymmetry is reflective of the California water market, where urban, high-value agricultural and environmental water purchasers have demand that is more inelastic than the supply elasticity of low-value agricultural growers who are likely to be selling water.

Table 2 indicates predicted prices and trade quantities for each market structure, under each state of nature. The predictions listed in Table 2 are for a setting with no supply risk. Figure 1 illustrates the shift in supply and demand functions resulting from varying the initial endowment and the resulting market equilibrium price and quantity in each state of nature. Maximizing total gains from trade generates the predicted competitive price, quantity, and earnings levels; dominant buyer revenue maximization generates the dominant buyer predictions.[9] Having the two sets of supply and demand functions allows for a comparison of the effect of supply and demand symmetry on market outcomes in the presence of supply risk.

Results

We conducted two analyses, one for the full data set, and one with a subset of markets. Not all subjects immediately understood the market trading environment, due to the complexity of the experiment. Patterns of price, quantity traded, and earnings reflect learning “on the job." However, subjects within some markets never fully grasped the double auction market structure for multiple contract instruments or the nature of the uncertainty even by the end of the experiment, as evidenced by falling earnings over time

[9] Although a dominant buyer in a nonuniform price auction such as this one could in theory perfectly price discriminate so as to increase monopsony rents even further, this did not happen in the lab.

or unusual pricing patterns. Consequently we focus here on the analysis of a subset of the markets, with 13 of the 58 markets removed from the analysis.[10]

Part 1 results. Regardless of treatment, subjects in each market first participated in eight periods of trading with no supply risk. Figure 2 shows average coupon price in the competitive and dominant buyer markets with Set A supply and demand functions, for each of the eight periods. The state of nature, which was known to the subjects during these training periods, is indicated at the bottom of the figure (dry, normal, or wet). Also included are two dashed lines indicating the theoretically predicted competitive and dominant buyer equilibrium prices, respectively. As the state of nature is known to the subjects while they are trading, price is inversely proportional to water availability in each year.

Equilibrium prices are close to predicted prices from period 1 onwards. Average water qualities traded are lower than predicted in both the competitive and dominant buyer cases (Figure 3). Equilibrium prices and quantities within Set B markets, where the cost functions of buyers and sellers are asymmetric, also track predicted prices and quantities, though not quite as closely as those of Set A. This is likely a function of the fact that it is more difficult for subjects within Set B markets to determine a strategy for trading when both equilibrium price and quantity vary by year type.

Figures 2 and 3 indicate that by the conclusion of Part 1, a sufficient number of subjects understood the basic experimental setting to generate market-level prices and

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[10] In particular, six of the 35 dominant buyers ended the experiment with negative earnings and within five of the 25 competitive markets, at least one buyer or seller ended the experiment with negative earnings equal to twice the amount of the show-up fee. In seven of the 30 markets with options, equilibrium option price at the end of the experiment was closer to the theoretically expected water price than to the theoretically expected option price, indicating confusion within the market regarding the purpose and inherent value of an option. The cardinal rankings of the coefficient point estimates on the smaller data set were the same as those of the full data set, though fewer coefficients on the full data set were statistically significantly different than zero.

traded quantities that respond to changes in availability of the risky input from period to period. These certainty results can consequently be used as a benchmark for the Part 2 results described below; any subject confusion in Part 2 can be attributed to the introduction of supply risk and option contracts rather than confusion regarding the basic trading environment.

Part 2 results. Subjects were introduced to input supply risk at the start of Part 2. Once subjects no longer knew their initial endowment of the input while trading, their bidding behavior changed significantly. Namely, price no longer responded to variability of water supply. This is illustrated in Figure 4, which depicts the prices for each transaction within a single competitive market. (Supply risk was introduced at the vertical line.)

Figure 5 graphs average prices within each period, by treatment. As in Figure 2, the state of nature is indicated at the bottom of the figure (dry, normal, or wet). T-tests comparing treatment means indicate some differences across treatment. Competitive treatment prices are statistically greater, on average, than those of the dominant buyer treatments (p=0.00). When options are introduced, competitive water market prices decrease (p=0.00) but those of dominant buyer markets do not (p=0.78). Controlling for market structure and period, markets where options can be traded exhibit lower water price variability than no-option markets. Also included at the bottom of Figure 5 are the average option prices for each of the two treatments where option trading was permitted. There is a distinct downward movement in option price over the course of Part 2, indicating that significant learning regarding the value of an option occurs during the experiment itself. Option prices in the competitive and dominant buyer markets are on average not statistically significantly different from each other (p=0.42).

Figures 6 and 7 indicate how many coupons were purchased on average within competitive and dominant buyer treatments, respectively, as well as how many options were purchased and exercised on average within the two option treatments. The state of nature in each period is also indicated along the bottom of Figures 6 and 7. T-tests comparing treatment means indicate significantly fewer water units traded in dominant buyer markets than competitive markets (p=0.00). However, when exercised options are included, the quantity of water units traded is higher on average within competitive markets (p=0.00). Within both market structures, subjects substitute away from water to options when such contracts are available to them. The inverse relationship between water availability and the number of options exercised indicates that subjects tend to exercise their options to purchase water in dry years. Further, it is interesting to compare the total number of coupons exchanged—coupons traded and, where permitted, options exercised—for each of the four treatments. The two treatments where options can be traded have higher variability in number of coupons purchased between periods, as subjects in the with-options treatments have the opportunity *ex post* to adjust the number of coupons they purchase.

These figures provide a graphical representation of the relative prices and quantities of the four treatments. We next perform a more rigorous statistical comparison between treatments. Bidding and trading activity in the early trading periods is more likely to reflect subject learning than profit-maximizing trading behavior. To account for learning, we discount early periods before subjects understood the game by utilizing the asymptotic convergence technique of Noussair, Plott and Riezman (1995), adapted from Ashenfelter et al. (1992). In the two equations that follow, the dependent variable y_{it} is the variable of interest observed within market i at time t: water or option prices, number of water or option units traded, earnings, or number of options exercised.[11] The convergence equation for the first four of these variables is the following:

$$y_{it} = B_{11}D_1(1/t) + B_{12}D_2(1/t) + ... + B_{1i}D_i(1/t) + ... + B_{1n}D_n(1/t) + B_2(t-1)/t + Cost_i + Water_{t-1} + u, \quad (1)$$

The variable B_{it} is the estimated coefficient on the variable of interest within market i at time t. The variable D_i is a dummy variable equal to 1 for market i and 0 otherwise and is weighted by $1/t$ so that later periods receive greater weight in the determination of the dependent variable of interest. The technique is effectively a weighted fixed effects linear regression, with later periods weighted more heavily than earlier periods, where all markets within a treatment are forced to converge to a single coefficient, B_2. The variable $Cost_i$ is a dummy variable equal to 1 for Set B markets and 0 otherwise. Subjects may formulate their expectations regarding some variables with the previous water year's conditions in mind even though they are told the events are independent. We thus control for lagged water year, $Water_{t-1}$, in calculating the asymptotic coefficients for price and number of units traded for both water and options.

The remaining two variables of interest, earnings and number of options exercised, are more likely to be influenced by current water conditions. Earnings are lower when less water is available, and the decision to exercise options is made ex post, with full knowledge of current water conditions. The asymptotic equation for earnings and quantity of exercised options is thus:

[11] The dependent variable of interest "number of water units traded" includes exercised options.

$$y^*_{it} = B_{11}D_1(1/t) + B_{12}D_2(1/t) + ... + B_{1i}D_i(1/t) + ... + B_{1n}D_n(1/t) + B_2(t-1)/t + Cost_i + Water_t + u,$$
(2)

In equations 1 and 2, the variable $Cost_i$ is equal to 1 if buyers and sellers in the market have asymmetric cost functions and is equal to 0 otherwise. The asymptotic coefficients from this convergence process are reported in Table 3.[12] Estimates are corrected for heteroskedasticity and autocorrelation using the Prais--Winsten transformation.

The price, quantity, and earnings estimates in Table 3 are the basis for comparing the relative efficiency of the four treatments. Correcting for autocorrelation reveals autocorrelation ρ-coefficients close to ρ =.90 for some treatments. Each market therefore really provides only one observation rather than independent observations for each of the 14 periods of Part 2. Thus the pairwise t-test comparisons are based on the number of markets within a treatment rather than the number of markets times the number of periods within a treatment.

An important research question of this paper concerns efficiency: Does the introduction of an option market in addition to the spot market increase efficiency? Even though the option market environment is more complicated, the answer is clearly affirmative:

Result 1. Allowing options to be traded increases efficiency in both the competitive and dominant buyer cases, as measured by market earnings. The ability to trade options increases market earnings on average by 63% for competitive markets and 67% for dominant buyer markets. Buyers are able to make additional beneficial trades after the water type is revealed and thus increase earnings. That earnings are higher

[12] Table 3 reports price, quantity and earnings levels on the combined data of sets A and B. Results on Sets A and B individually do not differ significantly from those presented in Table 3, other than that there is insufficient data in some cells of Set B to perform standard hypothesis tests.

where options can be traded in spite of the increased complexity associated with participating in two markets simultaneously strengthens our finding that options increase gains from trade. These gains were realized during dry periods, reflecting subject use of options to manage supply uncertainty.[13]

We find no statistically significant difference between treatments in option price, option trades, or options exercised. This is likely due to the fact that subjects may use the option market in a variety of ways to increase their earnings. These multiple strategies do not necessarily aggregate nicely to clear-cut, treatment-wide predictions of price and quantity.

That the introduction of options does not only result in higher efficiency in the competitive markets but also in the market with monopsony is important for California, where substantial political discussion surrounds the role of the MWD as dominant buyer. The basis of this discussion, the potential for market power, is reflected in the experimental results comparing treatments without options and partly in the results comparing treatments with options (Result 2). The most remarkable result is the lack of statistical significance between earnings in the two types of markets when options can be traded (Result 2a):

Result 2. The presence of a dominant buyer in the market induces fewer trades and lower water prices relative to the competitive case in markets with and without options. Total earnings are also lower in monopsonistic markets when options are not available. Result 2a. Earnings are not statistically different between competitive markets and markets with a dominant buyer when options are available. In the markets without

[13] Regression results demonstrating that both buyers and sellers have increased earnings during dry periods due to options are available from the authors on request.

options, the number of water units traded (including options exercised) is 25% lower in the dominant buyer treatment relative to the competitive treatment. Water price decreases by 20%, and earnings are lower by 27%. In the markets with options, the number of water units traded is also 25% lower in the dominant buyer treatment relative to the competitive treatment, though water price decreases by only 5% and earnings are not significantly different from each other.

The smaller decreases in prices and earnings when options are present may be due to the fact that when options can be traded, the dominant buyer's attention is divided between the water and option auctions. It may also be the case that the supply risk diminishes the ability of dominant buyers to fully exploit their market power. Sellers retain more surplus in the dominant buyer markets than the competitive buyer markets, as water price in the dominant buyer markets does not fall by as much as in the competitive buyer markets.

Result 3. The ability to trade options generally induces lower water prices in the competitive market but has little effect on price and quantity in the dominant buyer market. In competitive markets, water prices are 12% lower when options can be traded. The number of water units traded in auction decreases by 15%, though when options exercised *ex post* are also counted, water transferred actually increases by 8%. In dominant buyer markets, water prices increase by 5% when options can be traded. However, the ability to trade options has no statistically significant effect on the total number of water units transferred within dominant buyer markets.

One of the biggest obstacles for the political acceptability of any change in market institutions for California water markets does not concern efficiency, but fairness and equity—a new market instrument might increase overall efficiency but will the dominant buyer be able to absorb all gains for itself? Theory is silent on distribution of GFT from adoption of options. The answer found in the data of our experiment, however, is an unambiguous “no.” To the contrary, adding options lessens the vastly unequal distribution of gains from trade between the competitive sellers and the dominant buyers:

Result 4. Options increase distributional equity between buyers and sellers. Our results indicate that sellers increase their percentage of total gains from trade when options are available, in both the competitive and dominant buyer markets. Particularly, and most importantly for California, the extremely one-sided distribution of gains in the dominant buyer treatment without options becomes more evenly distributed once options are available (Table 4). Some of this increase in GFT to sellers likely results from the purchase and exercise of options at relatively high prices in earlier periods, but not all of it; in later periods when markets have converged on option prices, seller GFT is still higher in markets where options can be traded.

A final result concerns the experimental design: In one third of our experimental markets, traders were given asymmetric cost functions, which better reflects real-world conditions in California.

Result 5. Asymmetric buyer and seller cost functions have minimal effect on price, quantity, and earnings. Although there are not sufficient degrees of freedom in the data to generate asymptotic convergence coefficients specifically for each cost function, we include an indicator variable for cost function in the convergence coefficient regressions presented in Table 3. As measured by this indicator variable, the asymmetric cost function has no statistically significant effect on earnings or price. Quantity of water transferred is lower when the cost function is asymmetric.

Conclusion

Option markets are not well-developed in California. Options are more complicated than straightforward water transfers and politically less acceptable, yet they have the potential to increase earnings and enable additional transfers on the margin. Within the experiment, we find evidence that overall earnings increase with the addition of options, and, particularly in the important case of the existence of a dominant buyer, that this increase evens out the distribution of gains from trade. There is also a statistically significant increase in the number of water units transferred in both the competitive and dominant buyer markets, though the increase is not economically significant. Within our experiment, competitive option prices are 19% of water prices within the same treatment; dominant buyer option prices are 27% of water price. Bilateral option contracts in California have option values approximately 10% of the underlying value of water. Thus, our results are high relative to those observed in California option markets. Option price in most markets continued to decline in the latter periods of the experiment. If there had been more periods, option price would have likely continued to decline, perhaps to levels as low as those observed in existing bilateral contracts in California. Second, in order to isolate the effects of options, this experiment does not permit banking. If subjects had been able to store water across periods, option value as a percentage of water price may have been even closer to premiums observed in existing bilateral contracts in California.

This analysis provides practical insights into the design of water options markets by isolating the effects of market concentration and the availability of different contract instruments on the efficiency of markets. Earnings of subjects within the laboratory setting increase on average by 46% for competitive markets and by 63% for dominant buyer markets when options are available. The experimental markets described here are thin, as are the wholesale water markets they represent. Although the experimental setting abstracts away from many features of a real water market, the laboratory results do show that it is possible for thin markets to converge to relatively competitive price and quantity levels in the presence of water supply risk.

Water policymakers throughout the western United States are thinking about ways to manage the next multi-year drought. When California next experiences a series of dry years, CDWR and other policymakers within the state may once again consider a market for water options, as they last did in 1994-95, so that negotiations occur well in advance of need and sellers are compensated for sharing water supply risk. Future experimental research in this vein may explore the effect of the variance of water supply on option price and quantity traded, as forecasts of available water supplies in California incorporate new infrastructure and climate change predictions. Exploring the relationship between annual options and multiple-exercise options which can be exercised a pre-specified number of times over the course of a longer-term contract may also be of interest. Such contracts could provide water-exporting agricultural communities with additional certainty regarding future water supplies to help them cope with third-party impacts of water exports.

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Figure 1. Market Equilibrium Conditions by Year Type for Set A (Symmetric) (left side) and B (Asymmetric) Cost Functions

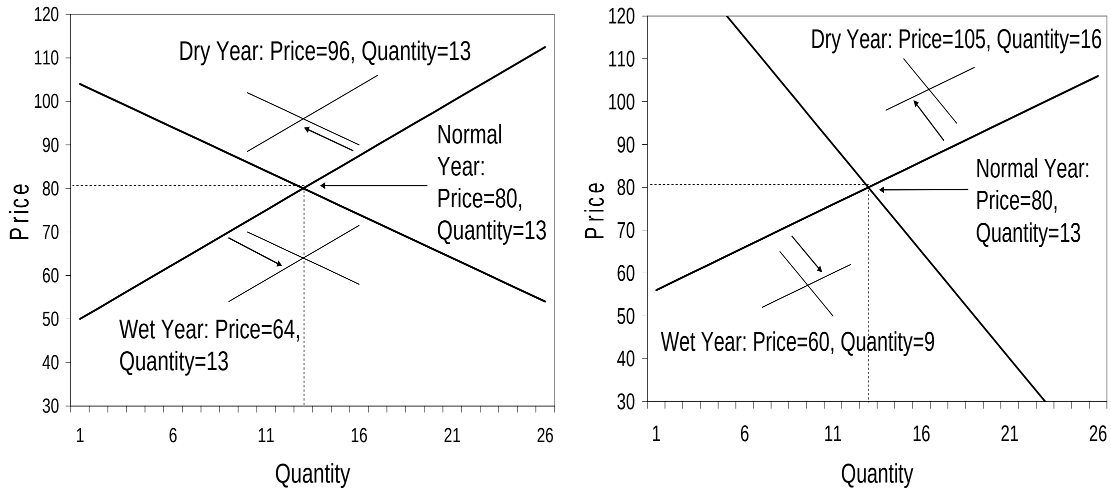
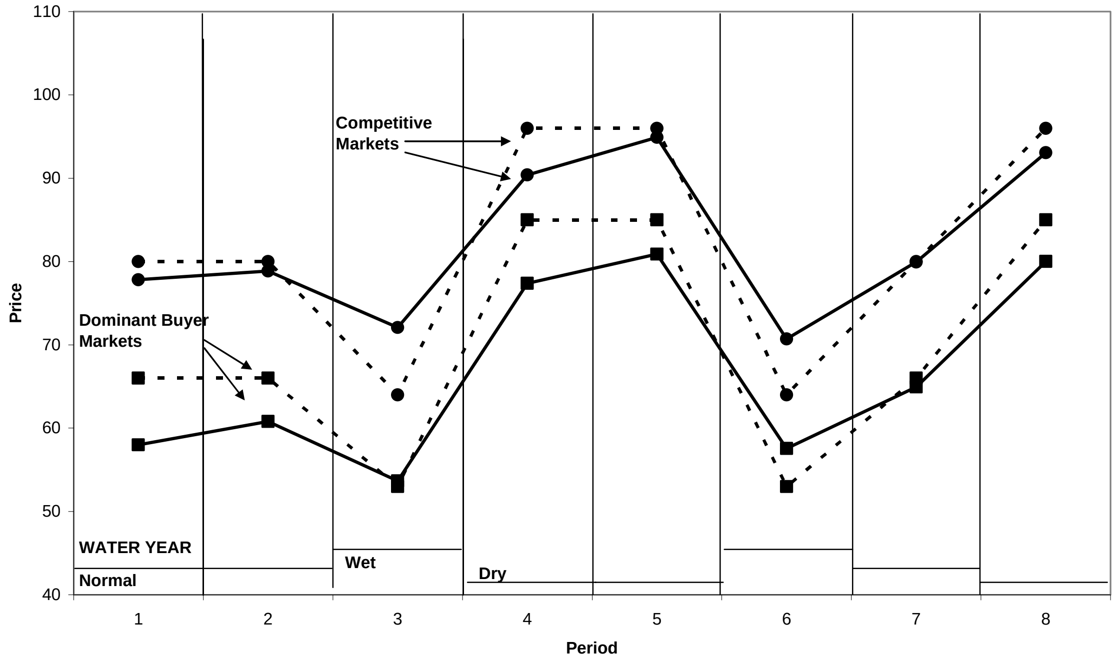
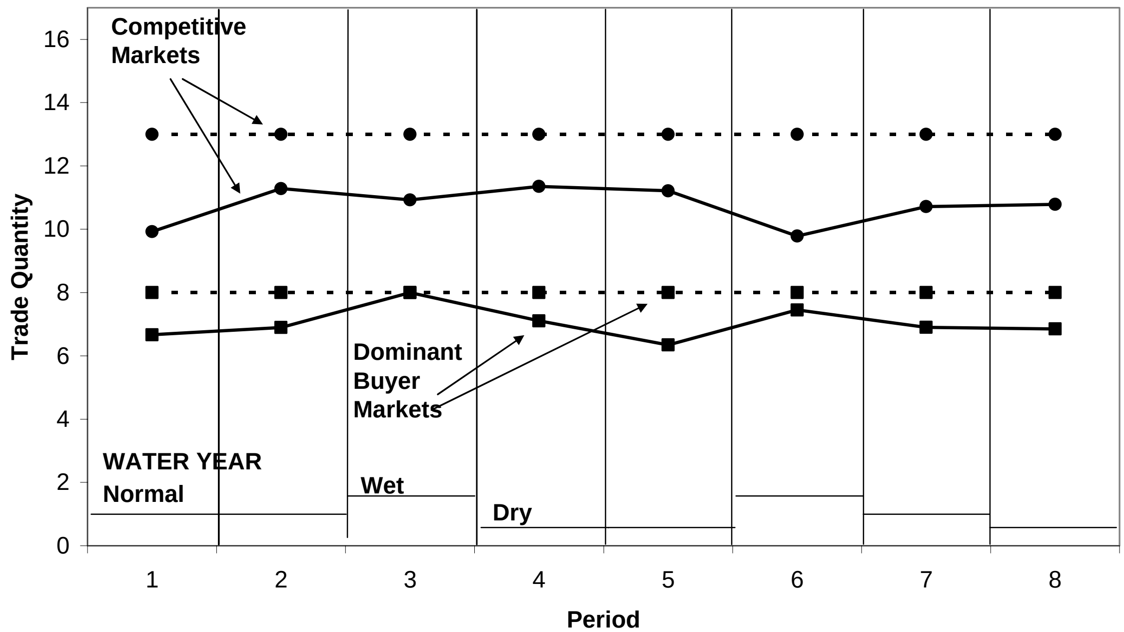


Figure 2. Per-Period Water Prices in Part 1 (No Supply Risk), Set A



Note: The dashed lines indicate theoretical water price predictions in competitive and dominant buyer markets, respectively.

Figure 3. Number of Trades in Part 1 (No Supply Risk), Set A



Note: The dashed lines indicate theoretical predictions of water units traded in competitive and dominant buyer markets, respectively.

Figure 4. Water Prices Over Time in a Single Competitive Market with No Options (Market #5)

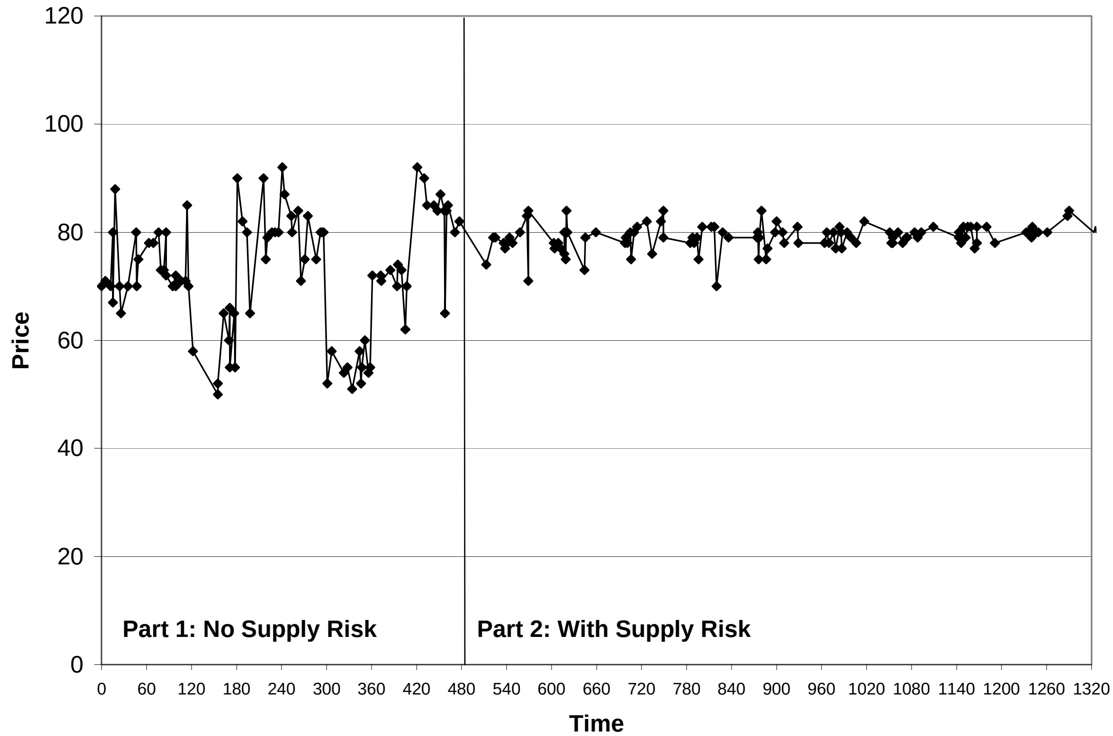


Figure 5. Per-Period Water and Option Prices by Treatment in Part 2 (With Supply Risk)

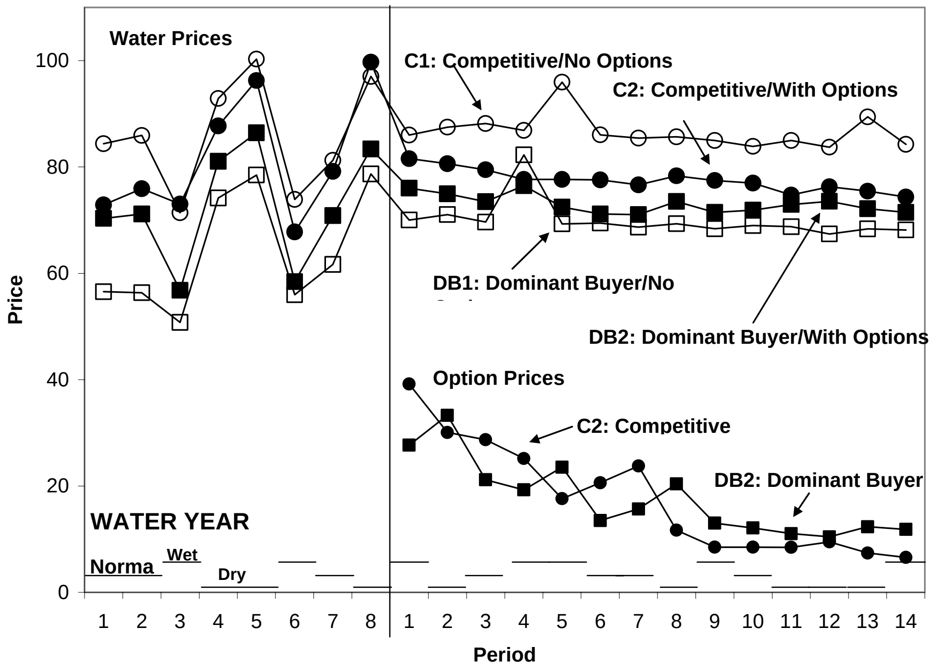


Figure 6. Number of Water and Option Trades by Treatment, Competitive Markets in Part 2 (With Supply Risk)

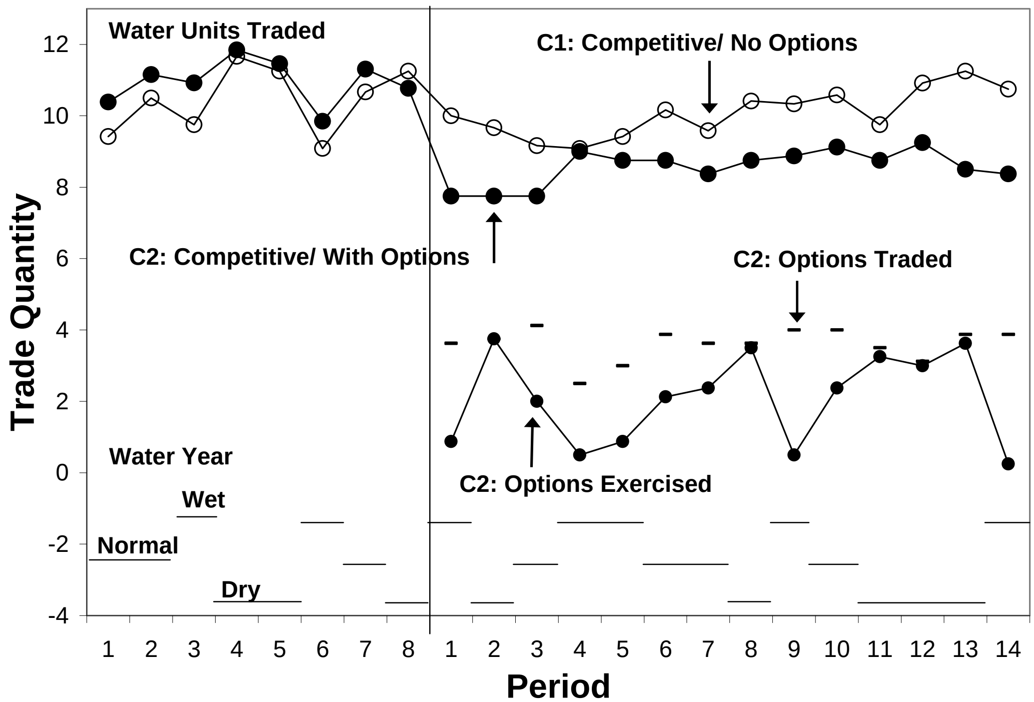


Figure 7. Number of Water and Exercised Option Trades by Treatment, Dominant Buyer Markets in Part 2 (With Supply Risk)

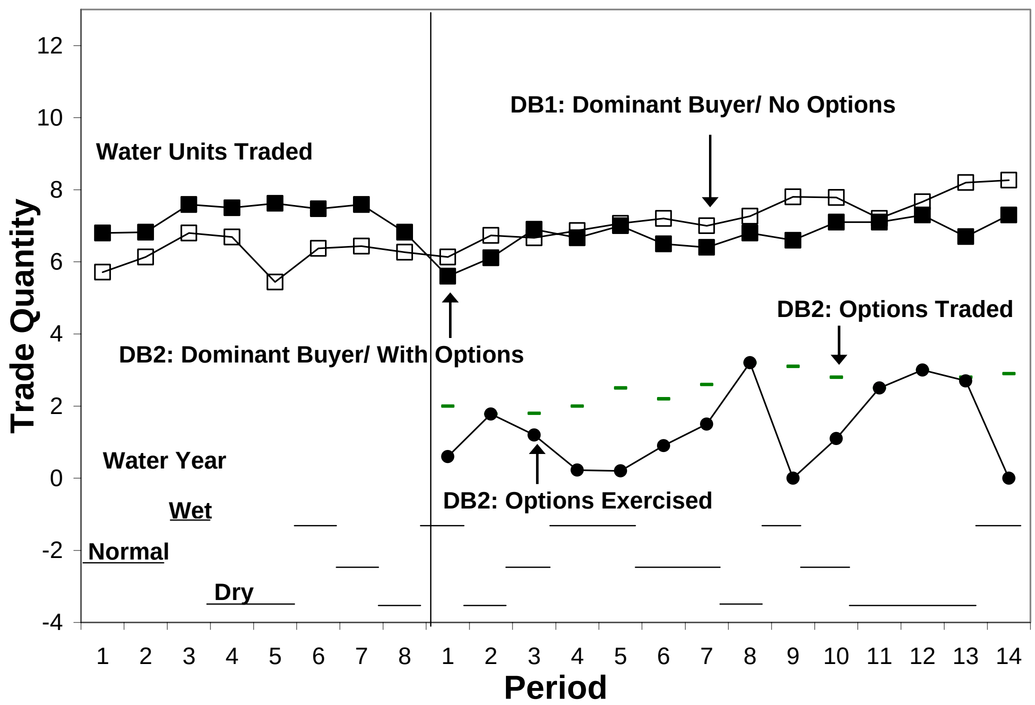


Table 1. Experimental Sessions Summary

Set A Supply and Demand Functions (symmetric)			Number of Observations		
Treatment Name	Dominant Buyer	Options	Sacramento State	UC Davis	Total
C1a	No	No	4	4	8
C2a	No	Yes	4	4	8
DB1a	Yes	No	6	6	12
DB2a	Yes	Yes	7	5	12

Set B Supply and Demand Functions (asymmetric)			Number of Observations		
Treatment Name	Dominant Buyer	Options	Sacramento State	UC Davis	Total
C1b	No	No	2	2	4
C2b	No	Yes	3	2	5
DB1b	Yes	No	2	2	4
DB2b	Yes	Yes	2	3	5

Table 2. Theoretical Predictions with No Supply Risk

	Price		Quantity	
Set A	C	DB	C	DB
Dry	96	85	13	8
Normal	80	66	13	8
Wet	64	53	13	8

	Price		Quantity	
Set B	C	DB	C	DB
Dry	105	94	16	12
Normal	80	74	13	10
Wet	60	52	9	7

Table 3. Price, Quantity, and Earnings Levels in Part 2 (With Supply Risk)

	Earnings	Water Price	Water Trades	Water Trades and Exercised Options	Option Prices	Option Trades	Exercised Options
C1: Competitive/No Options	198.45	85.40	10.94	10.44			
	(13.47)***	(1.89)***	(0.65)***	(0.57)***			
C2: Competitive/With Options	290.69	75.17	9.28	11.23	13.99	3.65	2.15
	(27.80)***	(1.08)***	(0.79)***	(0.79)***	(7.31)*	(.89)***	(0.34)***
DB1: Dominant Buyer/No Options	144.38	68.23	8.28	7.80			
	(11.33)***	(1.48)***	(0.59)***	(0.53)***			
DB2: Dominant Buyer/With Options	235.70	71.43	7.48	8.47	19.32	2.33	1.36
	(33.40)***	(1.33)***	(0.69)***	(0.83)***	(4.03)***	(0.54)***	(0.29)***
Cost Function (=1 for Set B Markets)	47.10	0.16	-1.83	-1.50	3.39	0.35	0.19
	(24.08)	(1.67)	(0.57)***	(0.63)**	(8.44)	(0.32)	(0.14)
Water_t	1267.78						-0.50
	(8.05)***						(0.06)***
Water_t-1		0.24	0.01	-0.01	-0.06	0.00	
		(0.50)	(0.01)	(0.01)	(0.06)	(0.01)	
Autocorrelation coefficient (rho)	0.20	0.14	0.77	0.71	0.91	0.88	0.39
Number of Observations	630	582	627	627	197	627	629
R-squared	0.9821	0.9726	0.6629	0.7045	0.5137	0.1685	0.3465
p-values for F-test of equivalence of coefficients between treatments:							
C1 - C2	0.0017	0.0000	0.0745	0.3797			
DB1 - DB2	0.0096	0.0804	0.3275	0.4710			
C1 – DB1	0.0043	0.0000	0.0005	0.0001			
C2 – DB2	0.1928	0.0150	0.0615	0.0129	0.4848	0.1987	0.8060

Notes: Each column is a single regression, convergence method of NPR 1995 etc. Standard errors in parentheses. * indicates 10%; ** indicates 5%; *** indicates 1%. Number of markets differs because some markets are dropped due to collinearity. Lagged water year coefficients and their standard errors are omitted for space reasons.

Table 4. Distribution of Gains from Trade

Competitive Treatments	Buyer Earnings	Seller Earnings	Market Earnings	Percentage of Earnings to Buyers
C1 (n=12)	55 (21.54)**	142 (19.23)***	176 (12.02)***	28%
C2 (n=8)	139 (16.61)***	152 (28.80)***	287 (33.65)***	48%
Increase in GFT from Adding Options				

Dominant Buyer Treatments	Buyers	Sellers	Market Earnings	Percentage of Earnings to Buyers
DB1 (n=15)	141 (15.73)***	2 (12.02)	161 (15.85)***	98%
DB2 (n=10)	127 (14.87)***	106 (31.57)**	269 (63.63)***	54%
Increase in GFT from Adding Options			67%	

Notes: Buyer, seller, and total earnings are the average per-period earnings of buyers, sellers, and buyers and sellers combined, within a treatment. All coefficients are asymptotic convergence coefficients calculated according to Noussair, Plott, and Riezman (1995). For this reason, buyer and seller earnings do not sum to the market earnings within a given treatment. “Percentage of Earnings to Buyers” is buyer earnings divided by the sum of buyer and seller earnings.