Valuing Options in California Water Markets: A Laboratory Investigation

Kristiana Hansen,* Jonathan Kaplan, Stephan Kroll, and Richard Howitt

May 31, 2007 Version

Selected paper prepared for presentation at the American Agricultural Economics
Association Annual Meeting Portland, Oregon,
July 29-August 1, 2007

* Kristiana Hansen is a graduate student in the Department of Agricultural and Resource Economics, University of California, Davis. Jonathan Kaplan and Stephan Kroll are Assistant Professors in the Department of Economics at California State University, Sacramento. Richard Howitt is Professor and Chair in the Department of Agricultural and Resource Economics at the University of California, Davis. Corresponding author: hansen@primal.ucdavis.edu

Abstract. Risk and reliability dominate water supply discussions in the arid western United States. In the past, water managers built additional storage to mitigate supply risk. The optimal, least expensive storage sites have now been taken, and there are strong, environmental objections to new facilities. Reliability of existing supplies is further diminished due to concerns about endangered species and global climate change. Thus water agencies increasingly turn to contractual mechanisms such as dry-year options to manage supply risk in advance of need. However, 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. How do market structure (competitive versus market power) and option contract availability affect water price and allocation within a market? Experiment participants trade stochastic realizations of water in a non-uniform double auction parameterized to resemble the California water market. We find that realized gains from trade are on average higher when options can be traded, by 11% in competitive markets and by 21% in dominant buyer markets. Findings in this analysis may assist policymakers in preparing for the next multi-year drought in California.

I. Introduction

Water is a scarce resource in California. Population and environmental demands on existing water supplies will continue to increase in the coming years. Water markets have developed in California in response to spatial and temporal variation in precipitation and delivery. Flexible arrangements for trading water, such as option contracts, should even further increase allocative efficiency of water over time and space. Under a typical option agreement, a water agency pays an option premium in the fall for the right to purchase water from the 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 native 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).

In this paper we use experimental economics to elicit information on efficiency gains from the use of options in water markets. Specifically, we use the controlled laboratory environment to isolate the effects of market concentration and contract availability on the efficiency of markets, in a way that is impossible with the minimal data on existing water options contracts that is currently available. The laboratory allows us to observe behavior in the presence of input supply uncertainty, where the uncertainty is driven by stochastic realizations of a natural resource input. Variability in water supply from year to year in California creates non-convexities which may lead to different outcomes than what we would expect to observe in a static environment with no uncertainty. We also alter the structure of the market in half the experimental sessions, to observe what happens in the presence of a single dominant buyer. This is in response to the reality that existing bilateral options in California are primarily purchased by a single entity, the Metropolitan Water District of Southern California (MWD). Thus, experiments allow us to test for the first time the effects of market structure and contract availability on water market efficiency.

The article is organized as follows. Section 2 explains the importance of options to the California water market and the reasons for conducting a laboratory experiment to study them. Section 3 describes the parameters and procedures employed in the experiment. Section 4 describes the results. Section 5 concludes.

II. Background

The first formal instance of water transfer under dry-year options in California occurred at the tail end of the multi-year drought of the early 1990's. The California Department of Water Resources (CDWR) implemented a dry-year options bank in the fall of 1994. Ten agencies purchased options to buy water with an exercise date of May 1995 from five sellers (Jercich 1997).[1] Although none of the options were exercised due

---

[1] The option price was administratively set at \$3.50/af by the DWR after consultation with the buyers and sellers. The exercise price was \$36.50-41.50/af.

to late rains in the spring of 1995, the presence of interested buyers and sellers indicates there could be interest in a state-sponsored options market again in response to the next multi-year drought.

Although the CDWR does continue to offer a Dry Year Water Purchase Program under which it facilitates water transfers during drought years, state-sponsored dry-year transfer activity since the drought option bank of 1994-95 has been minimal.[2] However, several California urban water agencies have entered into bilateral temporary transfers of water with agricultural water users which have many of the key characteristics of annual water options agreements. The San Diego Counter Water Agency receives up to 200,000 acre-feet (af) annually from Imperial Irrigation District under a 75-year contract, through fallowing during the first 15 years and through efficiency improvements in later years (SDCWA 2002). MWD has a 35-year fallowing agreement with irrigators in the Palo Verde Irrigation District , for up to 111,000 af annually (MWD 2007). MWD also signed annual option agreements with Sacramento Valley irrigation districts in 2003 and 2005 and exercised the option on 147,2000 af in 2003 (MWD 2003). This evidence of bilateral option contract activity suggests that the California water market may have developed to the point that water agencies who would benefit from annual dry-year options are able to undertake negotiations and implement such contracts without state involvement.

Regardless of whether future option agreements take place under the sponsorship of a state agency or bilaterally, there will be increased option activity in the future, because options have several important advantages over short-term leases and permanent transfers. Options where water is only transferred during dry years when water has the

---

[2] In 2001 and 2002, the only two years since 1994 that have been categorized by CDWR as dry, approximately 114,000 af and 17,000 af, respectively, were delivered under the Dry Year Water Purchase Program (CDWR 2004a, CDWR 2004b).

highest scarcity value are less objectionable to exporting communities than permanent transfers, or than leases which occur every year (Howitt, Moore, and Smith 1992, Dixon, Moore, and Schechter 1992, Coppock and Kreith 1993). Options often require less regulatory oversight than permanent transfers, as impacts to the environment and third parties are smaller when transfers are temporary (Hanak 2005). Finally, the San Luis Canal, the state-operated, 500-mile canal which conveys water from the Sacramento-San Joaquin River Delta to population centers in southern California is more congested in wet years, making conveyance in dry years easier to acquire.

Options negotiated in advance and contingent upon future water availability have two advantages over short-term leases negotiated only in dry years, after water conditions are known. First, time-consuming negotiations over price and terms of a water transfer occur in advance of when the water is needed. Second, an option premium which is paid to the seller regardless of whether the water is transferred could help resolve different preferences of buyers and sellers regarding the timing and manner of transfer.

An example of how the options structure could facilitate short-term transfers is the CDWR Emergency Drought Bank of 1991, which was the precursor to the 1994 Drought Options Bank discussed above. The 1991 Drought Bank was formed quickly during the spring of 1991, when it became clear that 1991 was going to be as dry as the three previous years had been.[3] The Drought Bank was to facilitate the short-term transfer of water from low-value agricultural users to higher-value agricultural and urban

---

[3] In 1991, the first year of the Drought Bank's operation, CDWR acquired 821,045 af from willing sellers at a price of $125/af. CDWR delivered 389,770 af to 12 urban and high-value agricultural agencies at a price of $175/af. The difference in sale and purchase price covered administrative costs and conveyance losses through the Delta. The difference in sale and purchase quantity is due to carriage losses through the Delta and the fact that less water was ultimately demanded by contractors than originally expected. (264,000 af was kept in storage until the following year.) The Drought Bank also operated in 1992 and 1994, though on a more modest scale (Jercich 1997).

water users on a temporary basis. Contracts were finalized and signed only weeks before water was transferred. Howitt, Schechter, and Moore (1992) report that buyers and sellers alike would have preferred more time for negotiations and greater certainty earlier regarding terms of water transfer.

Justification for experimental approach. All indications are that water in California will become increasingly scarce over time. Analysis of existing option trading activity in California would provide valuable information to policymakers regarding who benefits from option agreements, and what impediments prevent more extensive use of such flexible contract arrangements. However, although use of option agreements is growing, the number is still small enough that formal quantitative analysis of existing data is difficult. In California, even during dry years, markets are still relatively thin; trades that occur through market-based prices rather than administratively set prices are even rarer. Further, 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 2004), but neither study was able to perform formal tests of efficiency, for lack of sufficient data.

Due to this lack of data, we 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 successfully in the past to test alternative institutional designs and facilitates the design of workable policies before they are needed. Recent examples include Murphy *et al*. (2000) on the benefits of water market implementation and Poe *et al*. (2004) on the design of ambient-based pollution controls.

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, allowing them the opportunity to mitigate unforeseen problems before costly or irreversible decisions have been made.

III. Experimental Design

Parameters. We are interested in what effect the ability to trade annual options would have on the California wholesale water market. Purchasers of annual water options in California are likely to be high-value agricultural and urban water agencies. Sellers of water options in California are likely to be irrigation districts whose farmers can to some extent fallow lower-value crops, and the decision to fallow can be made just before planting would have occurred.

The experimental setting is a stylized model of the California water market. Buyers have value functions parameterized to mimic the incentives of urban and high-value agricultural water agencies who are willing to purchase water if the price is sufficiently low; sellers have cost functions parameterized to mimic the incentives of low-value agricultural water agencies who are willing to sell if the price is sufficiently high. Supply is more elastic than demand in our model, as is the case in the California water market.

The water and option auctions in this experiment reveal participants' willingness to pay, and sellers' willingness to accept, under four different market structures that are described in greater detail below.

The most notable feature of water supply in the western United States and California in particular is supply variability over time and space. Our 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.[4] Our experiment does not include a spatial element, as we model options traded at a single location. It is true that option value and usage would vary by location depending on hydrological conditions, storage reserves, and physical and financial constraints on conveyance. However, this analysis addresses the effect of option availability on water markets, and how impacts might vary with different market types. Multiple pricing points would have added complexity to the experiment without yielding much additional information.

Procedures. We conducted experiments in the fall of 2006 and the spring of 2007. Subjects were drawn from the undergraduate student population at the University of California, Davis at California State University at Sacramento.[5] Subjects were guaranteed a fee of $10 for arriving on time to their session. They also had the possibility of earning additional money during the experiment depending on their performance. Advertised average earnings for the experiment were $30, for a two-hour time commitment. Experimental sessions were conducted using the software program Z-Tree (Fischbacher 2007).

---

[4] 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 (CDWR 2007).

[5] Because undergraduate admission to UC Davis is more competitive than to CSUS, we had thought that experimental results might differ from school to school. However, there are no significant differences in behavior (in terms of market price, quantity traded, or earnings between the experimental sessions run at each of the two schools. Thus no distinction between experimental sessions run at the two universities will be made from this point onward.

Buyers and sellers trade water through a non-uniform price double auction according to the heterogeneous value functions assigned to them at the start of the session. However, subjects were informed only that they were trading a generic good used as an input into a production process which yielded them profits.

Regardless of the treatment to which they had been randomly assigned, all subjects first traded the generic good under conditions of certainty for eight periods, during Part 1 of the session. Each period, subjects learned before trading commenced the size of their initial endowment of the good for that period. The initial endowment of the input good varied from period to period depending on the state of nature. Subjects were informed at the start of each period whether the market was in state A, B, or C, corresponding—though unbeknownst to the subjects—to dry, normal, and wet years, respectively.[6]

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 a decreasing marginal cost function, or they could sell some or all of their initial endowment to buyers through the auction. Buyers could supplement their initial endowment of the good by purchasing additional units through the auction. The value and cost functions of buyers and sellers were parameterized such that positive gains from trade existed in each state of nature. 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

---

[6] There is no banking of water from one period to the next in this experiment. (The experiment is only dynamic in the sense that subjects draw on their experience in previous periods to form expectations about market price and quantity.) If our 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.

buying and selling the generic good in the auction and from profits from the sale of the final good.

At the conclusion of the training periods, subjects traded in Part 2 for 14 periods without knowing their endowment of the generic good. At the conclusion of each period, they learned how large their initial endowment had been at the start of the period 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. Subjects participated in one of four treatments, which varied by market concentration (competitive versus monopsony) and market institution (short-term contracts versus short-term contracts and option contracts).

The first treatment (C1) was a competitive market structure with four buyers and four sellers. Although initial endowment size varied from period to period according to the state of nature, all subjects within a particular period received the same endowment. The second treatment (DB1) was a dominant buyer market structure with one buyer and four sellers. A dominant buyer's initial endowment of the generic good was four times as large as that of a competitive buyer in the C1 markets.

In the third treatment (C2), 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. In the fourth treatment (DB2), subjects with the dominant buyer market structure traded options on the generic good as well as the generic good itself.

IV. Results

Basic experimental results. The experiment consists of 58 market observations involving more than 300 participants. 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. Within Set B, the demand function is more inelastic than the supply function. Table 2 indicates predicted prices and trade quantities for each market structure, under each state of nature. The predictions listed in Table 2 are static and contain no supply risk. Maximizing total gains from trade generates the predicted competitive price, quantity, and earnings levels; dominant buyer revenue maximization generates the dominant buyer predictions.[7] 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. We will see that although the inelastic demand function in Set B more realistically models the California water system, the subjects converge more quickly on the theoretically predicted price and quantity levels with symmetric supply and demand functions.

Part 1 results. Regardless of treatment, subjects in each market first participated in eight periods of trading with no supply risk. Although this part of the experiment was primarily intended as training, the results are interesting nonetheless. Figure 1 shows

---

[7] 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.

average coupon price in the competitive and dominant buyer markets with Set A supply and demand functions, for each of the eight periods. The large squares at the bottom of the figure indicate the state of nature (dry, normal, or wet), which was known to the subjects during these training periods. Also included are two sets of hash marks 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 availability of water in each year. Subjects appear to converge rather quickly on predicted prices. Figure 2 shows the same information for the Set B competitive and dominant buyer markets. Within Set B markets, there is movement towards theoretically predicted prices, though subjects do not converge to them as quickly as did the Set A markets.

Figures 3 and 4 indicate trade quantities for competitive and dominant buyer markets with Set A and B supply and demand functions respectively. The asymmetric supply and demand functions also made convergence to the theoretically predicted quantities more difficult.

Table 3 presents mean values for price, quantity, and market-level earnings for Set A competitive and dominant buyer markets. As these are training periods during which subjects are still accustoming themselves to the market environment and their supply and demand function parameters, the early periods are noisier than the later periods. Thus, the values reported here are for the last period under each state of nature. Further, reported prices are the last price in each period, in recognition of the fact that there is also a convergence process to a market price within each period. The final two columns of Table 3 contain static predictions for market equilibrium conditions under each state of nature. An asterisk indicates that the experimental results are statistically indistinguishable from the associated theoretical predictions regarding market behavior at the α=0.05 level. Table 4 contains the same information for Set B markets.

All markets converge to the theoretical price predictions by the conclusion of the training periods. Water quantities traded and earnings levels are generally lower than predicted. However, the Set A dominant buyer markets do trade the predicted quantity of water. Lower quantities and earnings are not surprising because the subjects are still acclimating themselves to the experiment during the training periods. However, quantities and earnings levels are also lower throughout Part 2 than static predictions would suggest. If the subjects have mostly figured out how the game works by the end of Part 1, then Part 1 is a benchmark level of understanding, indicating how much complexity is added to the experiment from the subject perspective by the addition of supply risk.

Part 2 results. The price series in Figure 5 illustrates the change in bidding behavior with the introduction of input supply risk. On the vertical axis of Figure 5 is lab dollars. On the horizontal axis is seconds elapsed in the experiment. The vertical lines demarcate the 60-second-long periods; the vertical line at time 0 is the break between Parts 1 and 2. Now that subjects trade water before learning their endowment of water in the current period, price no longer responds to variability of water supply.

Figure 6 graphs average prices. Each point in Figure 6 is the average of the last transaction price within each period, by treatment.[8] Competitive treatment prices are higher on average than those of the dominant buyer treatments. Although the presence of options does not seem to affect mean water price, cross-period variability in price does seem to diminish with options. This may indicate that options speed the rate of convergence to water market price.

---

[8] The graph of average water price per period by treatment does not look noticeably different than the graph of last water prices in Figure 6.

Also included at the bottom are the averages of the last option transaction 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.

Figure 7 indicates the quantity of coupons traded by period for each of the four treatments. The quantities for the two option treatments include exercised options. The series for the two treatments where options were traded have higher variability in number of coupons purchased, as subjects in the with-options treatments have the opportunity *ex poste* to adjust the number of coupons they purchase. Figure 8 indicates how many coupons were purchased for the C1 and C2 treatments, and how many options were purchased and exercised in the C2 treatments. Figure 9 provides the same information for the dominant buyer treatments. The state of nature in each period is indicated along the x-axis of Figures 8 and 9. Within both market structures, subjects substitute away from water to purchase options when such contracts are available to them Subjects in all treatments tend to exercise their options to purchase water in dry years.

Tables 5 and 6 calculate means for price, quantity, and earnings in each treatment several different ways. Column 1 of Tables 5 and 6 provides raw averages for price, quantity and earnings for C1 and C2 markets, and DB1 and DB2 markets, respectively.[9] To account for the fact that bidding in the early trading periods is more likely to reflect subject learning than profit-maximizing trading behavior, the first seven periods of trading are omitted from the averages. However, a more refined method for discounting early periods before subjects understand the game is to utilize the asymptotic convergence technique of Noussair, Plott and Riezman (1995), adapted from Ashenfelter (1992). The formula is as follows:

---

[9] Tables 5 and 6 report price, quantity and earnings levels on the combined data of sets A and B. Summary tables for Sets A and B are also available. Results for Sets A and B differ in some important ways. The differences are discussed below.

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

where y_{it} is the dependant variable of interest (observed price, quantity of trades or earnings level) within market *i* at time *t*, and B_{it} is the estimated coefficient on the variable of interest within market *i* at time *t*. The market indicator variable D_i is weighted by 1/*t*, so that later periods receive greater weight. 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 asymptotic coefficient B_2 from this convergence process for C1 and C2, and for DB1 and DB2, are reported in Column 2 of Tables 5 and 6, respectively.

We adapt the formula to our setting, as price, quantity, and earnings levels are influenced by the stochastic realization of available water supply from period to period, as well as by interaction between subjects within a market and the process of learning how the market works. In calculating the asymptotic coefficient for water price and number of trades in each treatment, we control for lagged water year, in recognition of the possibility that subjects formulate their expectations regarding current period's water price with the previous water year conditions in mind. In calculating the asymptotic coefficient for earnings in each treatment, we control for current water year. We also control for water year in calculating quantity of options exercised, as this decision is made *ex poste*, with full knowledge of current water supply conditions. Means reported in Column 3 are generated by the same convergence technique, now controlling for autocorrelation and cross-market heteroskedasticity.

One measure of the experimental results is whether they conform to theoretical expectations of what water and option prices, number of water and option trades, and earnings levels will be, given the market structure and contract offerings within each treatment.

According to the rational expectations model of behavior, subjects will purchase water and options at prices and quantities which maximize expected profits. Column 4 of Tables 5 and 6 gives theoretical predictions of price, quantity, and earnings levels for C1 and C2 and DB1 and DB2 markets respectively, which assumes that subjects play as if each year will be an average water year. Column 5 of Tables 5 and 6 indicates that for no treatment do experimental results match the predictions in Column 4. Noussair, Plott and Riezman (1995) similarly find that their experimental results do not conform to theoretical predictions. Our experiment has the added complication of water supply risk. Finding that our subjects do not conform to static theoretical expectations is thus definitely no surprise. One pattern observed thus far is the tendency of participants to smooth consumption over time rather than maximize net present value.

However, although price, quantity and earnings levels do not match these particular predictions, the convergence coefficients in Column 3 of Tables 5 and 6 can still be compared to each other. Parametric and non-parametric comparisons of equilibrium price, quantity, and subject earnings indicate the relative efficiency of the four treatments. Figures 10, 11, 12, and 13 provide a graphical representation of the point estimates for price, water quantity, option quantity, and earnings levels in Column 3 of Tables 5 and 6. All coefficients are statistically significantly different from one another at the $\alpha=0.05$ level.

Result 1. The presence of a dominant buyer in the market induces lower water price and fewer trades relative to the competitive case. This is definitely the case. Price, quantity, and earnings levels for DB1 are lower than for C1, within both Sets A and B.

Result 2. In both the competitive and dominant buyer cases, the presence of options generally induces lower water price and fewer trades. This is generally found to be true, though for competitive Set B markets, the presence of options increases water price very slightly. For dominant buyer Set B markets, the presence of options increases the number of water trades.

Result 3. In markets where options may be traded, the presence of a dominant buyer in the market induces lower option price and fewer option trades. Results regarding the interaction of the dominant buyer and the presence of options are mixed. Within Set A, option prices with a dominant buyer are lower, and quantities of options purchased and exercised are both higher, than with a competitive market structure. Within Set B, dominant buyer option prices are higher and quantities of options purchased and exercised are lower than competitive option prices and quantities.

Result 4. In both the competitive and dominant buyer cases, allowing options to be traded increases efficiency, as measured by market earnings. Earnings are higher in dominant buyer option treatments and in competitive option treatments within Set A. Earnings for the competitive option treatments within Set B are lower than earnings for the competitive no option treatments within Set B. Judicious removal of outliers may shed some light on whether the different results from Sets A and B are due to different supply and demand functions or due to insufficient data. Putting aside this issue for the moment, Table 7 indicates that for pooled data set, the presence of options increases market earnings on average by 11% for the competitive markets and 21% for the dominant buyer markets.

V. Conclusion

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 11% for competitive markets and by 21% for dominant buyer markets. There are some unusually high and low changes in earnings within these averages. Work continues on understanding the experimental results.

The experimental markets described here are thin, as are the wholesale water markets they are intended to 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 input 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 reimbursed for adopting supply risk. Our future research in this vein may explore the effect of the variance of water supply on option price and quantity traded, as well as 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.

References

Ashenfelter, O., J. Currie, H. S. Farber, and M. Spiegal. “An Experimental Comparison of Dispute Rates in Alternative Arbitration Systems.” *Econometrica* 60 (1992): 1407-33.

California Department of Water Resources (CDWR 2004a). “Management of the California State Water Project.” Bulletin 132-02, Sacramento, CA, January 2004.

California Department of Water Resources (CDWR 2004b). “Management of the California State Water Project,” Bulletin 132-03, Sacramento, CA, December 2004.

California Department of Water Resources (CDWR 2007). “Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices.” http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

Coppock, R.H. and M. Kreith, Editors. *California Water Transfers: Gainers and Losers in Two Northern Counties.* Conference Proceedings (University of California Agricultural Issues Center and Water Resources Center), Sacramento, CA, November 1992.

Dixon, Moore and Schechter. “California’s 1991 Drought Water Bank: Economic Impacts in the Selling Regions.” RAND, 1993.

Fischbacher, Urs. “Z-Tree: Zurich Toolbox for Ready-Made Economic Experiments.” *Experimental Economics* 10(2007), 171-178.

Howitt, R.E. “Spot Prices, Option Prices and Water Markets.” In K.W. Easter, M.W. Rosegrant, and A. Dinar, eds. *Markets for Water: Potential and Performance*. Boston, MA: Kluwer Academic Publishers (1998):119-140.

Howitt, R.E., N. Moore and R.T. Smith. “A Retrospective on California’s 1991 Emergency Drought Water Bank. Prepared for the California Department of Water Resources, Sacramento, CA, 1992.

Metropolitan Water Department of Southern California (MWD 2003). “Improved 2003 Water Picture Allows Metropolitan To Decline Final Sacramento Valley Transfer Option.” Press Release, May 1, 2003.

Metropolitan Water Department of Southern California (MWD 2007). “Palo Verde Land Management, Crop Rotation and Water Supply Program at a Glance.” http://www.mwdh2o.com/mwdh2o/pdf/at%20a%20glance/Palo_Verde.pdf.

Murphy, J.J., A. Dinar, R.E. Howitt, S.J. Rassenti, V.L. Smith. “The Design of “Smart” Water Market Institutions Using Laboratory Experiments.” *Environmental and Resource Economics*. 17(2000):375-94.

Noussair, C.N., C.R. Plott, and R.G. Riezman. “An Experimental Investigation of the Patterns of International Trade.” *The American Economic Review* 85(1995):462-91.

Poe, G.L., W.D. Schulze, K. Segerson, J.F. Suter, C.A. Vossler. “Exploring the Performance of Ambient-Based Policy Instruments when Nonpoint Source Polluters Can Cooperate.” *American Journal of Agricultural Economics* 86(2004):1203-10.

San Diego County Water Agency (SDCWA 2002). “Historic Water Transfer Agreement Gets Final Approval as QSA Falters.” Press Release, December 31, 2002.

Villinski, M. “A Framework for Pricing Multiple-Exercise Option Contracts for Water.” PhD Dissertation, University of Minnesota, 2003.

Watters, P. “Efficient Pricing of Water Transfer Options: Nonstructural Solutions for Reliable Water Supplies.” PhD Dissertation, University of California, Riverside, 1995.

Table 1. Experimental Sessions Summary

Set A Supply and Demand Functions (symmetric)

	Dominant Buyer	Options	Number of Observations 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)

	Dominant Buyer	Options	Number of Observations 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

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

Set B	Price		Quantity	
	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 Results with No Supply Risk, Set A

	Experimental Results		**Predictions**	
	Comp	**Discrim. DB**	**Comp**	**Discrim. DB**
Last Dry Year (Period 8)				
Last Water Price	94.63*	85.29*	96	85
	(6.63)	(16.87)		
Number of Trades	10.63	6.88*	13	8
	(2.13)	(3.13)		
Earnings	-1132	-1184	-1086	-1128
	(31.6)	(77.45)		
Last Normal Year (Period 7)				
Last Water Price	77.75*	68.71*	80	66
	(7.43)	(10.8)		
Number of Trades	10.81	7.13*	13	8
	(2.01)	(3.78)		
Earnings	269	219	318	276
	(49.21)	(89.68)		
Last Wet Year (Period 6)				
Last Water Price	68.06*	55.58*	64	53
	(7.77)	(12.23)		
Number of Trades	9.88	7.63*	13	8
	(1.20)	(3.31)		
Earnings	1415	1379	1466	1424
	(29.56)	(77.66)		

Last Water Price is the average price of the last transaction in the period for all markets within the relevant treatments. (Last Water Price of 94.63 is the average last price of all markets in CB1a and CB2a; because options have not yet been introduced, these two treatments are as yet indistinguishable.) Number of trades is the average number of trades in the period for all markets within the relevant treatments. Earnings is the average of market-wide earnings of all markets within the relevant treatments.

For competitive market descriptive statistics, n=16; for dominant buyer markets, n=24. Standard errors of the averages are in parentheses. An asterisk indicates that the experimental result is not significantly different than the relevant theoretical predictions, at a significance level of α=.05.

Table 4. Price, Quantity, and Earnings Results with No Supply Risk, Set B

	Experimental Results		**Predictions**	
	Comp	**Discrim. DB**	**Comp**	**Discrim. DB**
Last Dry Year (Period 8)				
Last Water Price	96.33*	83.88*	105	94
	(24.44)	(14.48)		
Number of Trades	11.67	5.63	16	12
	(2.60)	(3.38)		
Earnings	-1069	-1387	-916	-1804
	(125.65)	(270.09)		
Last Normal Year (Period 7)				
Last Water Price	82.67*	65.33*	80	74
	(7.75)	(10.92)		
Number of Trades	11.33	6.78	13	10
	(1.50)	(3.83)		
Earnings	493	376.00	546	525
	(28.91)	(174.67)		
Last Wet Year (Period 6)				
Last Water Price	64.56*	50*	60	52
	(13.33)	(7.53)		
Number of Trades	8.78*	5.11	9	7
	(2.22)	(2.15)		
Earnings	1593	1566	1644	1356
	(39.70)	(63.64)		

Last Water Price is the average price of the last transaction in the period for all markets within the relevant treatments. Number of trades is the average number of trades in the period for all markets within the relevant treatments. Earnings is the average of market-wide earnings of all markets within the relevant treatments.

For competitive and dominant buyer market descriptive statistics, n=9. Standard errors of the averages are in parentheses. An asterisk indicates that the experimental result is not significantly different than the relevant theoretical predictions, at a significance level of $\alpha=.05$.

Table 5. Price, Quantity, and Earnings for Competitive Market Treatments, All Data

Competitive Treatment No Options

	Simple Average (Periods 8-14)	Convergence Coefficients	Convergence Coefficients Corrected for AR(1) and Cross-Panel Correlation	Theoretical Predictions	Significance (p)
Water Price	85.27	86.34	85.55	80	<0.005
	(11.25)	(1.38)	(0.17)		
	12	168	168		
Water Quantity	7.98	10.28	10.19	13	<0.005
	(2.29)	(0.18)	(0.12)		
	13	168	168		
Earnings	-177	224	225	386	<0.005
	(51.03)	(11.41)	(13.04)		
	12	168	168		

Competitive Treatment With Options

	Simple Average (Periods 8-14)	Convergence Coefficients	Convergence Coefficients Corrected for AR(1) and Cross-Panel Correlation	Theoretical Predictions	Significance (p)
Water Price	85.27	85.52	86.93	80	<0.005
	(11.25)	(2.32)	(0.08)		
	12	182	182		
Water Quantity	7.98	8.03	7.94	13	<0.005
	(2.29)	(0.22)	(0.08)		
	13	182	182		
Earnings	-116	258	256	386	<0.005
	(109.84)	(16.22)	(5.59)		
	13	182	182		
Option Price	38.07	34.6	31.81	8	<0.005
	(55.93)	(7.58)	(2.33)		
	13	165	84		
Option Quantity	3.02	3	4.34	3	<0.005
	(1.89)	(0.20)	(0.19)		
	13	182	84		
Water and Exercised Option Quantity	9.55	10.01	9.98	16	<0.005
	(2.08)	(0.22)	(0.07)		
	13	182	182		

Convergence coefficients are estimated by the weighted fixed-effects technique described in the text. Standard errors are in parentheses below the estimates; below standard errors are sample sizes.

Table 6. Price, Quantity, and Earnings for Competitive Market Treatments, All Data

Dominant Buyer Treatment No Options

	Simple Average (Periods 8-14)	Convergence Coefficients	Convergence Coefficients Corrected for AR(1) and Cross-Panel Correlation	Theoretical Predictions	Significance (p)
Water Price	84.66	67.71	70.33	74	<0.005
	(14.07)	(1.44)	(0.09)		
	13	223	196		
Water Quantity	7.52	7.5	7.85	10	<0.005
	(3.23)	(0.24)	(0.08)		
	16	223	196		
Earnings	-244	165	160	365	<0.005
	(72.91)	(10.06)	(12.51)		
	16	224	224		

Dominant Buyer Treatment With Options

	Simple Average (Periods 8-14)	Convergence Coefficients	Convergence Coefficients Corrected for AR(1) and Cross-Panel Correlation	Theoretical Predictions	Significance (p)
Water Price	73.87	73.63	76.66	74	<0.005
	(10.23)	(0.76)	(0.05)		
	17	225	168		
Water Quantity	6.28	6.46	7.37	10	<0.005
	(2.78)	(0.23)	(0.08)		
	17	225	168		
Earnings	-168	212	210	365	<0.005
	(205.48)	(18.78)	(5.22)		
	17	238	238		
Option Price	33.32	29.86	19.26	5	<0.005
	(30.65)	(2.49)	(0.56)		
	14	166	84		
Option Quantity	3.09	3.09	5.43	2	<0.005
	(3.13)	(0.24)	(0.40)		
	17	236	84		
Water and Exercised Option Quantity	8.21	8.24	9.14	12	<0.005
	(3.47)	(0.29)	(0.09)		
	17	225	168		

Convergence coefficients are estimated by the weighted fixed-effects technique described in the text. Standard errors are in parentheses below the estimates; below standard errors are sample sizes.

Table 7. Percentage Increase in Earnings Resulting from Presence of Option Contracts

Competitive Treatments

	Set A	Set B	Sets A and B
C1	-254	331	225
C2	229	311	256
Expected Earnings	227	386	284
Percentage Change	213%	-5%	11%

Dominant Buyer Treatments

	Set A	Set B	Sets A and B
DB1	-112	190	160
DB2	-59	274	210
Expected Earnings	185	365	234
Percentage Change	29%	23%	21%

Figure 1.

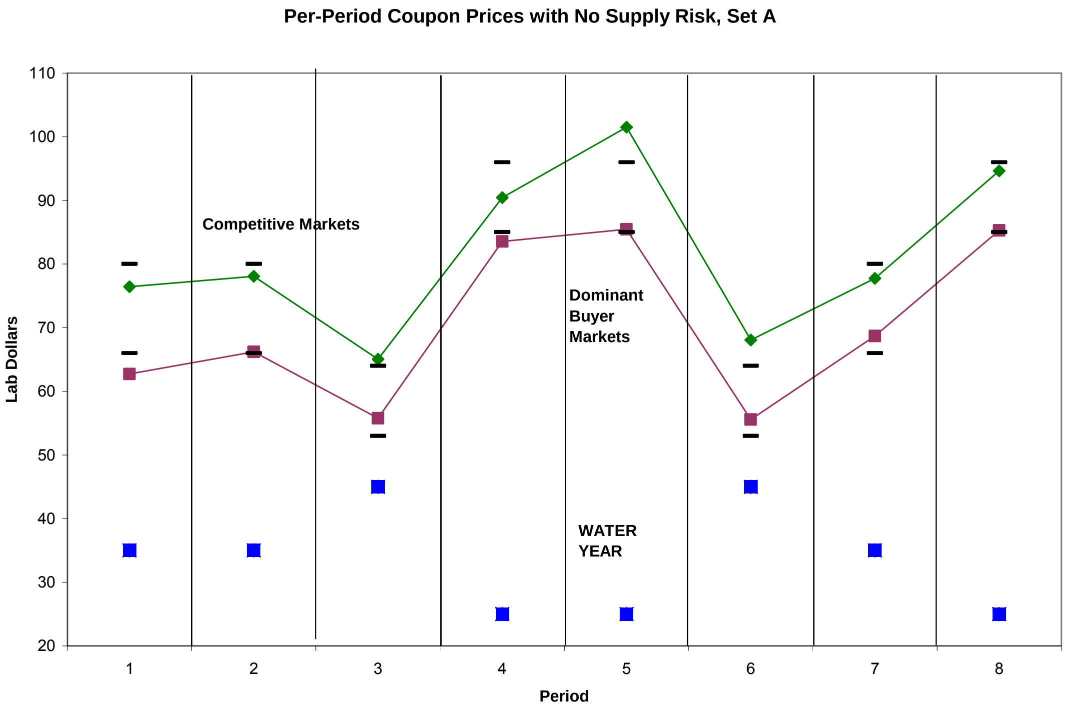


Figure 2.

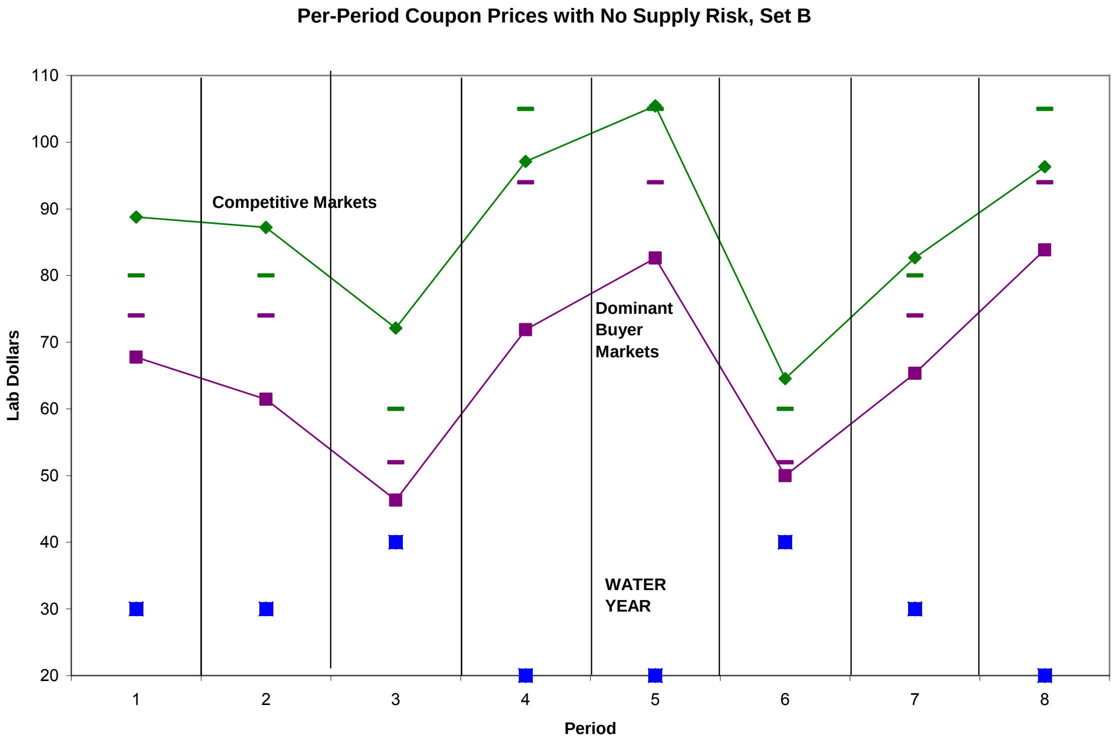


Figure 3.

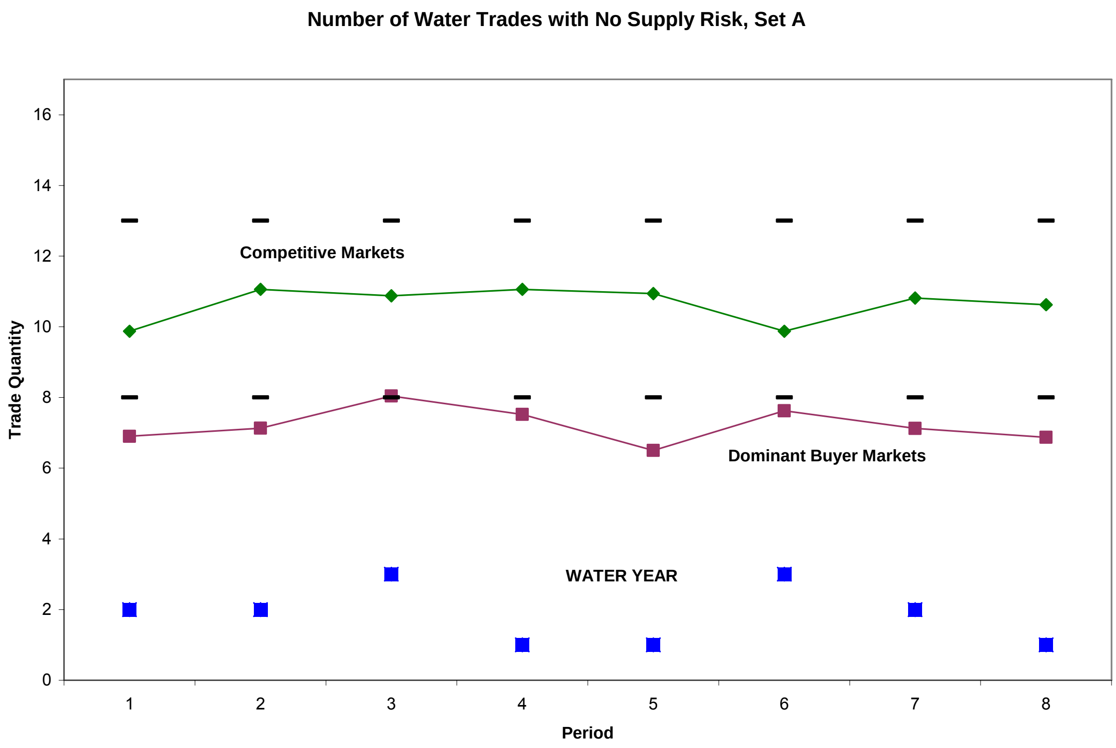


Figure 4.

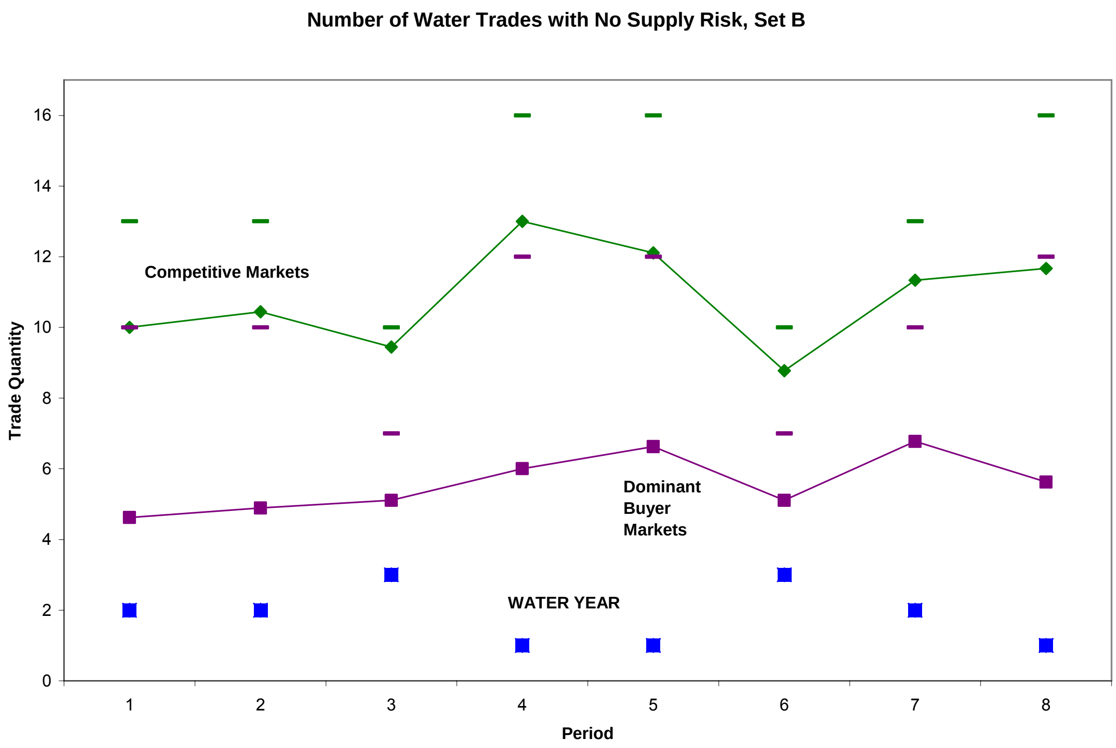


Figure 5.

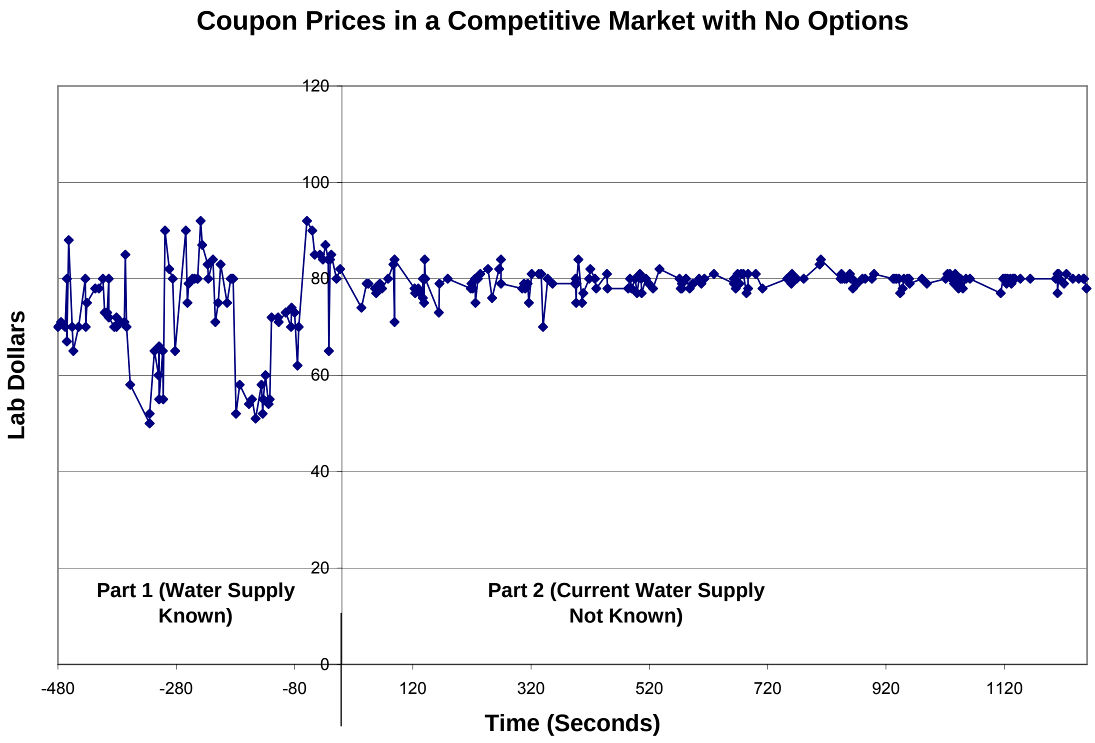


Figure 6.

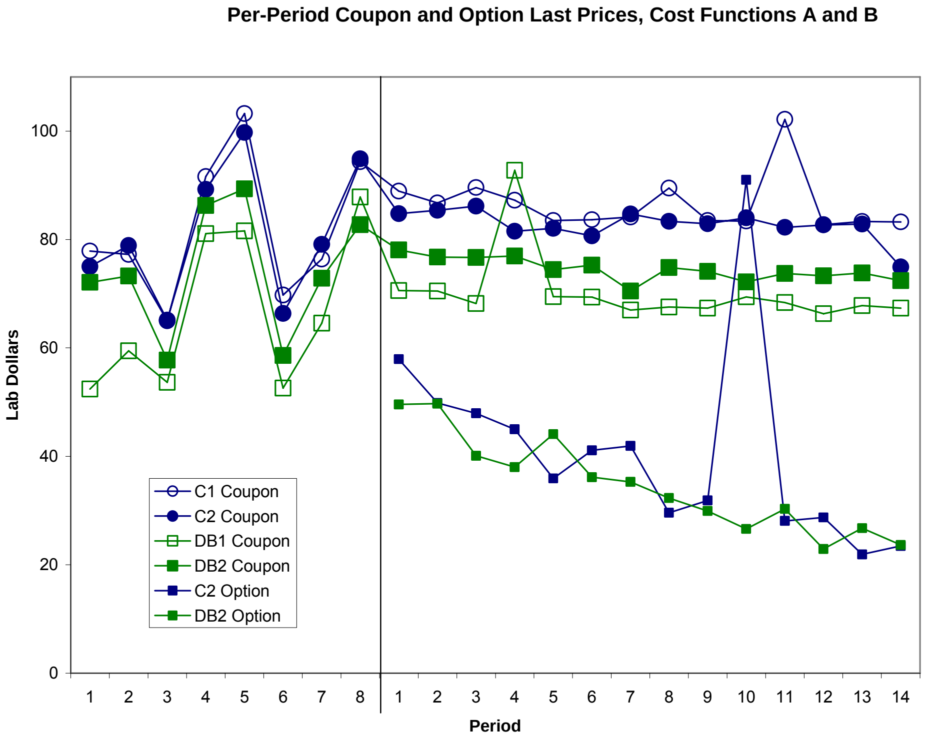


Figure 7.

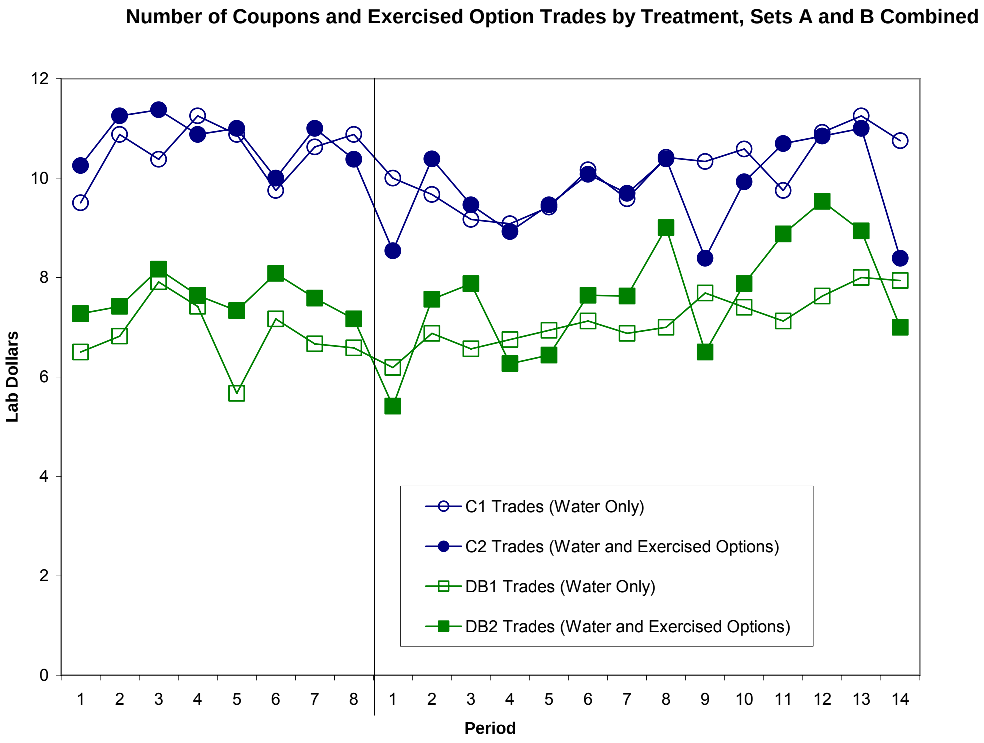


Figure 8.

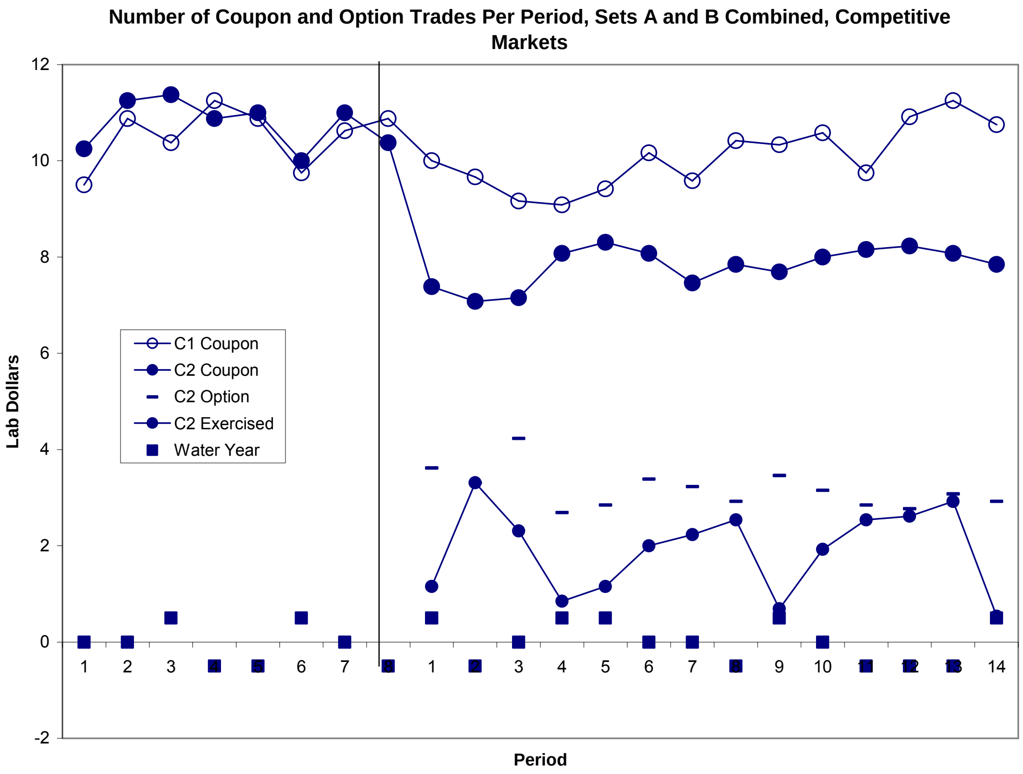


Figure 9.

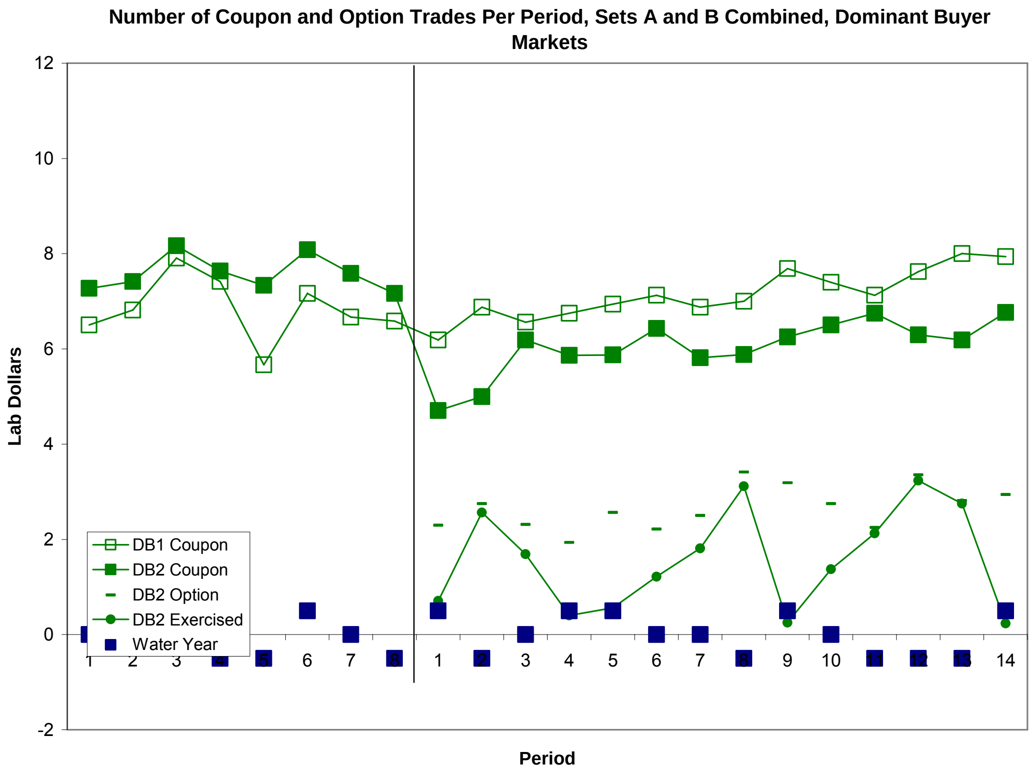


Figure 10.

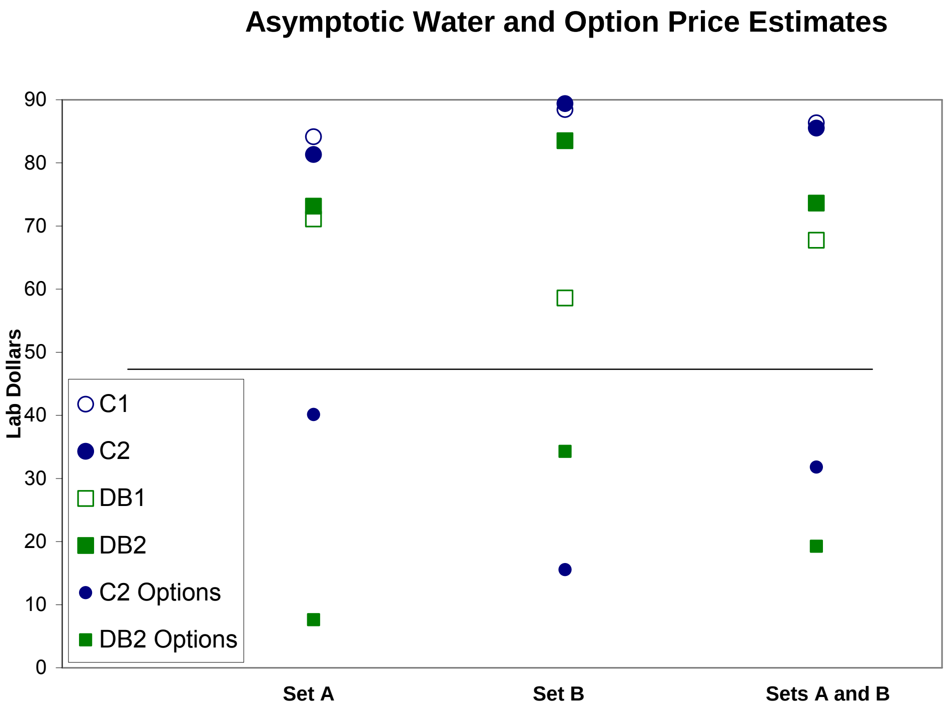


Figure 11.

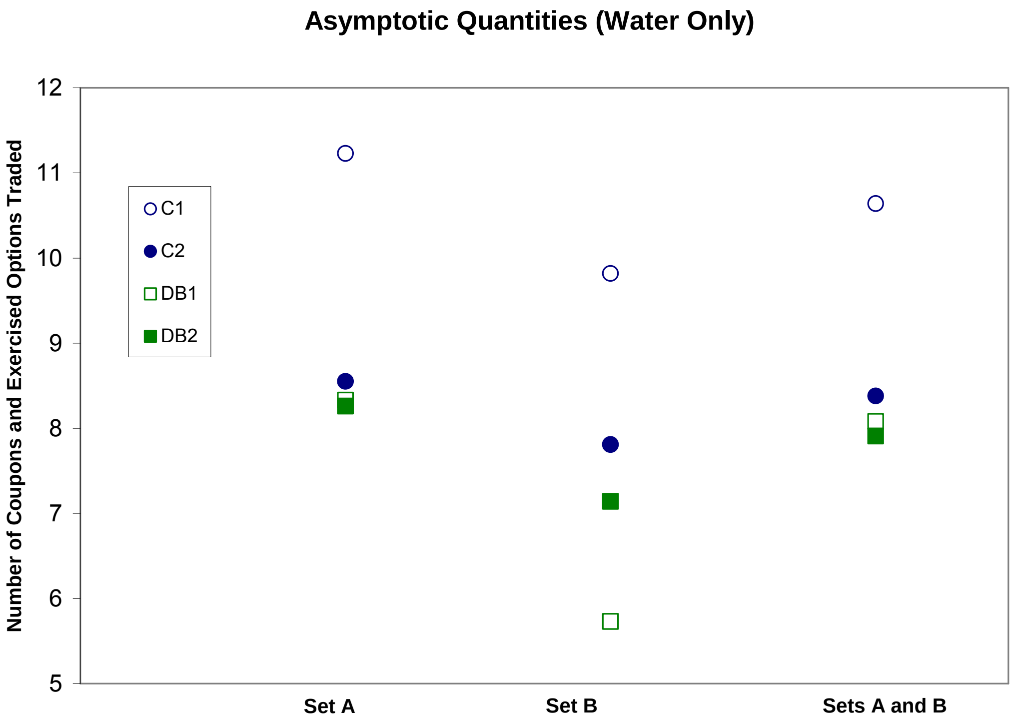


Figure 12.

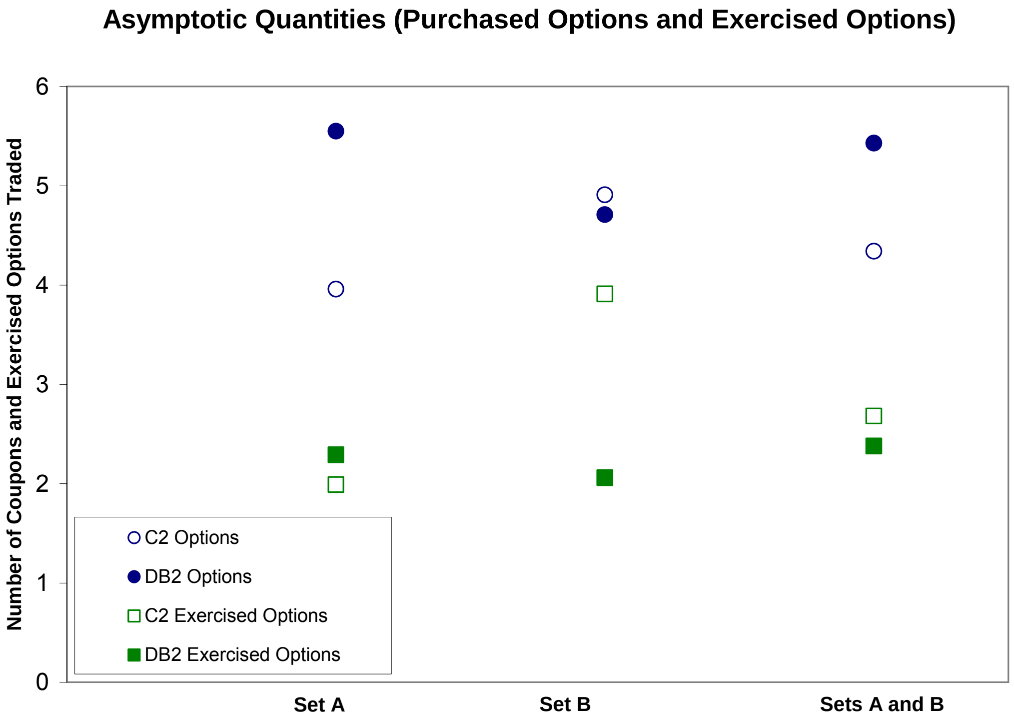
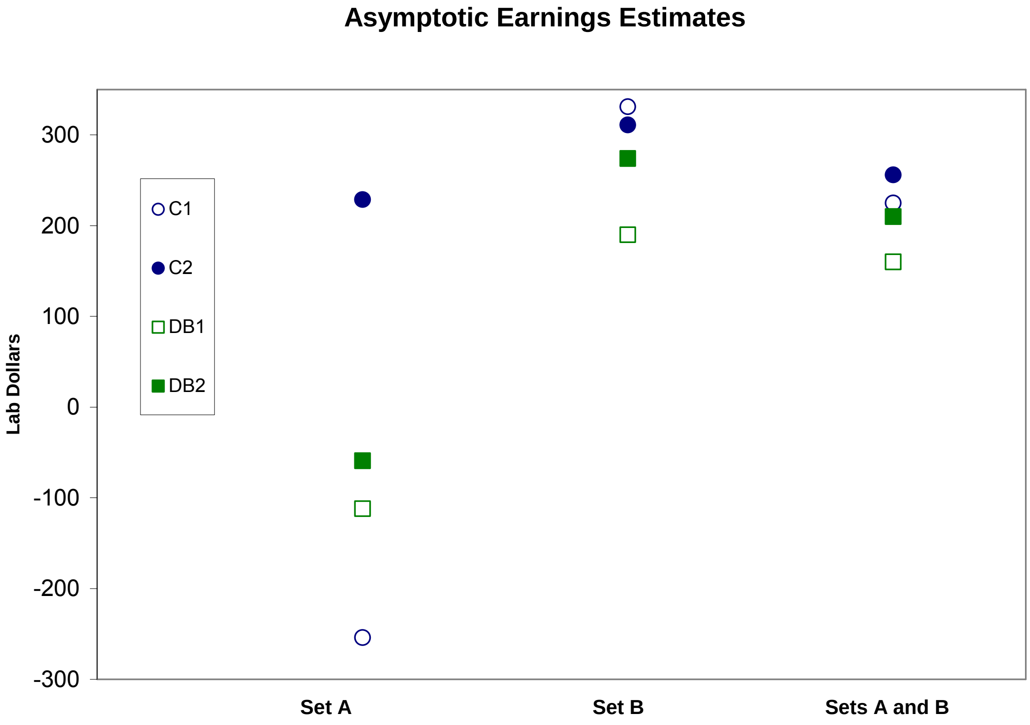


Figure 13.


Asymptotic Earnings Estimates
Lab Dollars
300
200
100
0
-100
-200
-300
○ C1
● C2
□ DB1
■ DB2
Set A
Set B
Sets A and B