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Multi-Unit Uniform Price Auction applied to the Metropolitan Water District of Southern California

Abstract:

The following Senior Honors Thesis is inspired by David Zetland's dissertation on the Metropolitan Water District. With the expertise of Prof. Michael Hanemann, it delineates a uniform-price multiunit auction used to achieve a better allocation of water. Specifically, it introduces a model for the demand functions for the different member agencies. Then, it uses those demand functions to run the auction. The results prove that uniform-price auction in the context of MWD achieves a more efficient allocation at a higher price than the Tier 2 rate it is compared to. In general, the thesis calls for more research in this topic specifically applied to the relationship between water purveyor and member agencies.

I) Introduction

On April 1, Jerry Brown ordered mandatory reductions in water use for the first time in California's history. Gov. Brown declared that people should realize we are in a new era. For over 10,000 years, 300,000 to 400,000 people inhabited this land. Today, 38 million people with 32 million vehicles strive to attain one of the highest levels of comfort on earth on the very same land. After a winter of record-low snowfalls, the state's four-year drought has reached near-crisis proportions. In an executive order, the Governor ordered the State Water Resources Control Board to impose a 25 percent reduction on the state's 400 local water supply agencies over the coming year. This reduction will impact 90 percent of California residents. The agencies themselves will have to devise restrictions to cut back on usage and to monitor compliance. Many farmers will not fall under the 25 percent guideline as they receive their water from other sources. Nevertheless, farms in general have already seen consistent cutbacks in their water allocations throughout the last few years. Furthermore, the owners of large farms will be required, under Mr. Brown's executive order, to provide detailed reports to state regulators about water use in order to decrease water diversion and waste. With the Californian snow-packs at only 6 percent of normal levels, Republican representatives are trying to push for the construction of two large water facilities whose development has been blocked by Democrats concerned about harm to the environment and damage to endangered species of fish. Water-use restriction will be enforced on golf courses and cemeteries. The executive order also calls for the State and the local governments to replace 50 million square feet of ornamental turf with less water-intense lawns.

Such a dramatic context and the need to enter a new era in the state's management of water calls for a sweeping reconsideration of Californian water policy. As much as a drastic reduction of water use is pivotal, it is also time to devise and to introduce more flexible and efficient pricing schemes between water purveyors and local water utilities. In particular, such pricing schemes need to take into account the limited supply of water that California faces and the different demands that different local water utilities incur. Ellen Hanak, from the Public Policy Institute of California, has advocated multiple times that linking water supplies and different water demands is key to set the right price. In my research thesis I focus on the Metropolitan Water District of Southern California, a consortium of 26 cities and water districts that provides drinking water to nearly 19 million people in parts of Los Angeles, Orange, San Diego, Riverside, San Bernardino and Ventura counties. More specifically, I attempt to address the current inefficient pricing system in order to improve water allocation, by charging more to the agencies that value water the most through an auction. In particular, inspired by Zetland's dissertation "Conflict and Cooperation within an Organization: a Case Study of the Metropolitan Water District of Southern California" and with the help of my research thesis advisor, Professor Hanemann, I developed a Uniform-Price auction model for MWD.

The paper is structured as follows. In the literature review I will provide some examples of research on auctions in relation to water and auction theory in general. In the background section I introduce some important information on MWD, the pricing system that it currently enacts and its inefficiencies as introduced by Zetland. In the model section I present the model devised to come up with the agencies' demand functions. Then, in the section about the auction itself, I explain how I ran the auction using the model developed in the previous section. Finally in the conclusion I summarize the paper's findings and touch on their significance.

II) Literature Review and Introduction to Auctions

The literature related to auctions as a means of water allocation has yet to be significantly developed. Nevertheless, many papers are of particular interest for this research as they shed light on different applications that have been used in different locations around the world. Simon and Anderson, in their paper "Water Auctions as an Allocation Mechanism in Victoria, Australia," review the six water auctions that took place in1988 and in early 1989. These auctions were perceived as an efficient and equitable mechanism to allocate limited water supplies to their highest value use. Even if the agricultural areas where the different auctions occurred were similar, there was substantial variation in the prices paid, which reflects varying demands for additional irrigation water. In Victoria, the participants in each auction, individuals with legal access to the river, were required to complete a preregistration form indicating the maximum quantity of water that they were interested in acquiring. Bidders competed on the basis of their willingness to pay for a single megalitre of water. The highest bidder could then purchase as much water as he or she desired at that price. Should additional water be available, then other bidders would be allowed to buy at that price. If the availability of water were less than the amount demanded by the highest bidder, then the bidding would be reopened. A reserve price of $AUS 100 per megalitre was set, based on an estimate of the financial benefits that could be gained by applying water to agricultural lands. To address equity issues in one particular auction seven stages were established with increasing following minimum purchases: Stage 1: 1 ML; Stage 2: 10 ML; etc. Overall, these auctions rendered the value of water more explicit. Also, the authors argue that the measure of the value provided by the auctions could provide guidance for further rationalization of water management.

In "Water Marketing – The Next Generation" Hill and Anderson introduce sealed-bid double auctions, repeated sealed-bid double auctions and live or sealed-bid double auctions for unique rights to design allocative mechanisms for Water Banks. The authors point out that sealed-bid double auctions with multiple buyers and sellers hold promise as a way to increase the efficiency of water markets. In this kind of auction, the bank arrays the selling bids in ascending order of reservation price and the buying bids in descending order of offer price. Then a market clearing price and volume can be identified and the gains from trade can be maximized. Several sealed-bid auctions could be held following any specific weather event or the traditional irrigation applications. Given the uniqueness of prior appropriation–water rights, live or sealed-bid auctions selling groups of rights are necessary in this case. The authors, concluding their chapter on water markets' increasing efficiency, suggest closed-bid double auctions that bring buy and sell bids together at appropriate trading dates as the primary trading system for stored water. For differentiated water rights they recommend live (English) auctions.

Auctions seem to be functional ways of dealing with water buybacks as well. "Using Laboratory Experiments for Policymaking: an Example from the Georgia irrigation Reduction Auction" by Cummings, Holt and Laury, reports a series of experiments that were used to design and implement an auction in a specific setting. In April 2000, the Georgia legislature passed a law mandating that the state hold an auction in drought years in order to pay certain farmers to curtail irrigation. In such a setting, farmers made offers to suspend irrigation for the rest of the year. These offers could be accepted or rejected by the EPD. In the experiments, the farmers themselves participated in a sealed bid (no revisions) discriminative auction. Before the results came out they also partook in a discriminative auction with revisions, in which information was released only on those permits whose offer was provisionally accepted. After attending one 42-person laboratory experiment and studying results from the other sessions, the EPD implemented a discriminative price auctions with revisions, with no maximum accepted price announcement and a random tie-breaking rule. Across revision rounds offers typically declined. Although the maximum accepted offer was not announced, only the ID numbers of the ones that were temporarily accepted were announced, and a certain amount of communication between farmers occurred so that partial imperfect information was in place. In general this paper takes an interesting approach. In fact, it stresses the importance of the context and the role of experimental economics in choosing the optimal auction procedure, in particular the pricing rule (uniform or discriminatory), the closing rule (with or without bid revision rounds), and if the provisional results are to be announced or not. “Auction Design for Water Buybacks” by Hailu and Thoyer takes on the same topic. The authors argue that multi-unit auctions are a promising mechanism for water buybacks. They construct an agent-based model of bidders to compare the performance of alternative procurement auction formats when bidders submit continuous bid supply functions and learn over time to adjust their bids to maximize their net incomes. This paper is particularly relevant for this thesis as both the Vickrey and uniform auctions are found to be viable options for bidder coordination for higher prices, especially when the population is heterogeneous and competition is low. The auction model investigated in the paper has a population of agents (farmers) selling water in a sealed-bid auction to a single buyer, the government agent. Bidding under the Vickrey, uniform and discriminatory pricing auctions were simulated with two populations of six bidders who had an aggregate capacity of 12, at different demand levels ranging in magnitude of aggregate supplier capacity. One population was homogeneous, with bidders having a maximum capacity of 2.0 units. The other was heterogeneous, with pairs of bidders having maximum capacities of 1.0, 2.0, and 3.0 units. For the homogeneous population of bidders, as predicted by the theory, learnt bidding strategies are closest to truthful bidding for the Vickrey auction, followed by uniform. Strategies are clearly less sincere under discriminatory auction. The results are very interesting for the heterogeneous bidder population. Both in the uniform and in the Vickrey auctions, it seems that larger bidders tend towards supply inflation while the smaller bidders are more truthful, "free riding" on the risks taken by the bigger ones. On the other hand, size has little or no effect under the discriminatory auction. Put aside the discussion on heterogeneity, the uniform and Vickrey auctions display more mixed strategies as opposed to discriminative. Furthermore, in terms of budget outlays the authors find that in general the Vickrey and uniform auctions are similar and lead to better efficiency and lower budget outlays. However, as competition decreases the picture is reversed. As explained later in the paper, Vickrey auctions are not very palatable for the cooperative format of MWD. This paper is then of particular interest as it specifically gives explicit motives to focus on uniform auctions from a perspective related to water markets.

The most important resource in reaching an understanding of how auctions function and in deciding on which kind of auction to focus in this paper has been "Auction Theory" by Vijay Krishna. Chapter 12 of the second edition takes over three kinds of sealed-bid auctions to sell identical units with decreasing marginal values: discriminatory auction, uniform-price auction and the Vickrey auction. In each of these auctions, the different bid vectors can be considered as inverse demand functions. In a discriminatory auction each bidder pays an amount equal to the sum of his winning bids. In a uniform-price auction all the units are sold at a "market-clearing" price such that the total amount demanded is equal to the total amount supplied. The book adopts the rule that the market-clearing price is the same as the highest losing bid. In this way, the number of units that a bidder wins corresponds to the number of competing bids that he defeats. For example, to win exactly one unit the bidder's highest bid must defeat the lowest competing bid, while the second highest bidder's bid must be less than the second lowest competing bid. In a Vickrey auction, if a bidder wins a specific number of units she pays that number of highest losing bids of the other bidders. In this scenario, to win one unit, the bidder's highest bid must defeat the lowest competing bid, to win a second unit the bidder's second-highest bid must defeat the second-lowest competing bid and so on. According to the Vickrey pricing rule the bidder has to pay the lowest competing bid for the first unit he wins, the second lowest competing bid for the second unit he wins and so on. The principle underlying the Vickrey auction is that each bidder is asked to pay an amount equal to the externality he exerts on other competing bidders. In chapter 13, Krishna studies the equilibrium bidding behavior and efficiency of the three kinds of auctions just described. An important assumption is that the marginal values are declining in the number of units obtained. As previously done with the bid vectors, we can easily invert each bidder's valuation vector to get her demand function. In a Vickrey auction it is a weakly dominant strategy to bid one's true demand function, even when bidders are asymmetric. In fact if a bidder reports a lower demand function, she ends up forgoing the surplus on the marginal units that she ends up not obtaining. Since the Vickrey auction does not cause any demand reduction, the allocations are efficient. On the other hand, the uniform-price auction is generally inefficient. Even if it is a weakly dominant strategy for a bidder to bid truthfully for the first unit, bidders have the incentive to shade their bids for any additional unit, or in other words to reduce their demand. Let's consider a bidder that bids on two units. An increase in the second bid has two effects: it increases the likelihood of winning the second unit and at the same time it increases the value of the highest losing bid if the bidder ends up not winning the second unit. When the second bid is close to the bidder's value of the second unit, the second effect dominates and the bidder has an incentive to shade her bid. Thus, the main difference between the two auctions is that in the uniform-price auction every bid other than the first may determine the price paid on all units while in the Vickrey auction a bidder's own bids do not determine the price paid. For what concerns discriminatory auctions, it is straightforward that there will be demand reduction as bidding the bidder's marginal value for any specific unit only ensures that there is no gaining from winning the unit.

Another paper relevant to this thesis is "Multi-unit Auctions and Competition Structure" by Préget and Thoyer. In this paper the authors compare two different competitive environments: the first includes six bidders with small individual demands, the second has two bidders with large individual demands. One prediction is that the revenue in the first scenario is higher as the 6 bidders can shade their bids on a smaller number of units than their two counterparts in the second scenario. Also, the second scenario made up of only two bidders calls for less competitive pressure and lower revenue. To predict the allocative efficiency is harder. We would expect misallocation to be higher in the second scenario as there is more demand reduction, but at the same time the risk of misallocation is lower by default where there are less bidders. The experimental results with uniform-price auctions confirm the predictions. They attest that when the number of bidders increases while individual demand decreases, there is less demand reduction. This leads to higher expected revenue with a lower variance. Nevertheless, the allocation efficiency does not change significantly.

The last paper used as a meaningful source of information on auctions is "Designing Auction Institutions for Exchange" by McCabe, Rassenti and Smith. In particular, this paper's discussion of the Vickrey auctions is very relevant. The Vickrey auction assumes that bidders increment the next higher bid by the minimum bid increment needed to maximize the value of winning. The authors find that in experiments the phenomenon of jump bidding, or increments high enough to exclude some of the remaining units being sold, appears. Nevertheless, this is unlikely to be an issue in the specific context of the Metropolitan Water District. In fact, the utilities that buy water from MET buy on such a large scale that they are very unlikely to increase the price paid by much at all, as that would result in consistent revenue losses.

III) Background on The Metropolitan Water District

The Metropolitan Water District of Southern California is a public agency composed of 26 member agencies, including 14 cities, 11 municipal water districts and one county water authority. MWD meets its service area's demand with water from the Colorado River via the Colorado River Aqueduct and from the State Water Project via the California Aqueduct. The 26 agencies deliver to their customers a combination of local groundwater, local surface water, recycled water, and imported water purchased from Metropolitan. Table 1 in the Appendix, taken from MWD 2014 Annual Report, summarizes the water use by Metropolitan's member agencies in acre-feet for the fiscal year 2013/2014.

Around 75 percent of Metropolitan's revenues come from volumetric water sales, which are very much affected by changes in weather and statewide water supplies. To mitigate this instability in water rates, Metropolitan maintains financial reserves to stabilize rates during times of reduced water sales. Also, to stabilize its revenue Metropolitan has started to generate a larger portion of revenues (about 20%) from fixed sources such as taxes, the Readiness-to-Serve Charge and the Capacity Charge (see the rate description below). Finally, about 7% of Metropolitan's revenue comes from interest income, hydroelectric power sales, rents and leases. As stated in the introduction, the following thesis branches off Zetland's dissertation on the Metropolitan Water District. Before introducing Zetland's discussion of MWD's pricing inefficiencies I wish to give an overview of its rate structures as presented in the last Water Management Plan. Below are the different elements that make up the price charged:

1. The System Access Rate (SAR) recovers the cost of providing conveyance and distribution capacity to meet average annual demands. It's a volumetric system-wide rate levied on each acre-foot of water that moves through the Metropolitan system.
2. The Water Stewardship Rate (WSR) recovers the cost of providing financial incentives for existing and future investments in local resources including conservation and recycled water. It's a volumetric system-wide rate levied on each acre-foot of water that moves through the Metropolitan system.
3. The System Power Rate (SPR) recovers the cost of energy required to pump water to Southern California through the SWP and Colorado River Aqueduct. The cost of power is recovered through a uniform volumetric rate.
4. The Treatment Surcharge recovers the costs of providing water service through a uniform, volumetric rate. The treatment surcharge recovers all costs associated with providing treated water service, including commodity, demand and standby related costs.
5. The Capacity Charge is levied on the maximum summer day demand placed on the system. It is meant to pay for the cost of peaking capacity on Metropolitan's system. These capacity charges are specific to each member agency, as they are intended to make the agencies decrease their use of the Metropolitan system to meet peak day demands and to increase demand in periods of time with lower use.
6. The Readiness-To-Serve Charge (RTS) recovers the costs of providing standby service, including emergency storage and those standby costs related to the conveyance and

aqueduct system. The RTS is allocated to the member agencies based on each agency's proportional share of a 10-year rolling average of all firm deliveries. A 10-year rolling average leads to a relatively stable RTS allocation that reasonably represents an agency's potential long-term need for stand-by service under different demand conditions.

7. The Tier 1 Supply Rate recovers the majority of the supply costs and reflects the cost of existing supplies. Each member agency has a predetermined amount of water that can be purchased at the lower Tier 1 supply rate in a calendar year. Purchases in excess of this limit will be made at the higher Tier 2 Supply Rate. The Tier 1 Supply rate includes a Delta Supply surcharge.
8. The Tier 2 Supply Rate reflects Metropolitan's cost of developing long-term firm supplies. Purchases in excess of the Tier 1 limit will be made at the higher Tier 2 Supply Rate. Member agencies must issue purchase orders (POs) to buy Tier 1 water. If they do not have POs or want to buy more than they are allocated with their POs, they pay the higher Tier 2 price. Since MET sets Tier 2 prices at marginal cost and targets zero-profits, Tier 1 prices are targeted below MET's average cost, so that Tier 2 sales subsidize Tier 1 sales.

Table 2, taken from the MWD 2014 Annual Report, summarizes all the rates charged by the MWD during the last 5 years. David Zetland, in "Conflict and Cooperation within an Organization: a Case Study of the Metropolitan Water District of Southern California" discusses all the inefficiencies that MET pricing system incurs in its present state. Under the conditions of self-interest and scarce goods, the members of a cooperative must have fairly homogeneous preferences for decisions that benefit all members to be made. As Table 1 shows, member agencies' dependence on MET differs, which entails heterogeneous preferences that lead to inefficiency. Also, MET does not have social preferences. In other words, the agencies' managers are more likely to represent their agency than Metropolitan as a whole. Given that the group welfare is not the overarching objective, the outcome is necessarily inefficient.

Concerning the very rate structure, Zetland critiques the practice of Postage Stamp Pricing (PSP), or selling each class of water (Tier 1 and Tier 2 for example) at the same price no matter where it is delivered. The PSP is inefficient for different reasons as Zetland argues. First of all, if the member agencies' willingness to pay for reliability differs, they should be allowed to pay for the reliability they want and the relative conveyance. Second, PSP combines different conveyances and waters into one good. In other words, MET has been averaging out the cost of waters coming from different sources so that in the end some specific sources look cheaper then they actually are. Third, member agencies use a combination of local water and MET water to meet demand. Such a diversification smoothens supply and reduces price oscillations, contradicting scarcity signals and discouraging conservation. Finally, PSP does not change with delivery distance. In this way, members that make significant use of infrastructure or require new infrastructure do not pay the marginal cost associated to their specific needs. Thus, PSP enforces a system in which member agencies do not contribute marginal revenue in proportion to marginal costs, making cross-subsidies likely. In order to allocate water supply and conveyance capacity among member agencies, Zetland argues that MET could use auctions. Since auctions are fast, fair and transparent, they can be used to allocate water more efficiently, reducing misallocation resulting from MET's current policy of postage stamp pricing. In particular, Zetland suggests an auction mechanism in which every day member agencies bid for a known quantity of water and conveyance. He then proposes an Ausubel auction, which is the open format version of the Vickrey auction, as the most politically viable auction format. If political practicality were really a priority, then it would be fair to recognize that a daily auction has some substantial impracticality to it. Moreover, the Vickrey auction is not practical given the cooperative format of MWD as it will be explained in the auction section. In the model offered in the following thesis, political viability and economic efficiency are both taken into account. As a consequence of that, a uniform-price auction is developed.

IV) The Model

In order to devise an auction between the water agencies that receive direct deliveries from the Metropolitan Water District there needs to be a sense of what each agency's demand function looks like. But beforehand the water allocation for the auction needs to be specified. As a starting point, this paper assumes that the water sold at Tier 2 would be a good amount of water to auction. In other words, each utility would pay the Tier 1 rate on the water bought within their Tier 1 limit. It would enter the auction only if its allocation were higher than that limit. Then, we extracted the 2014 Tier 1 limits per member agency from MWD's "Rate Structure Administrative Procedures Handbook 2013/2014". The Tier 2 column in Table 3 in the Appendix shows the amount of water bought at the Tier 2 price for the member agencies that passed their thresholds. Our objective being both an efficient allocation of water and a higher price for conservation purposes, we decided to broaden the pool of our auction by decreasing by 20% the Tier 1 thresholds. The "Unfilled Demand" in Table 3 shows the amount of water requested at the Tier 2 price with the new Tier 1 limits.

Having decided the amount of water to be auctioned, we proceeded in setting up the following model. Each agency's demand function is of the form:

$$q = a - bp \ (1)$$

We used the Tier 1 and Tier 2 prices from 2014 as our known marginal prices $p^I = 593$ and $p^I = 743$. With these marginal prices we observe the following demand functions:

$$q^I = a - bp^I \ (2)$$

We considered the current demand in terms of gallons per capita daily (look at column "Use" in Table 3) and we estimated what the maximum per capita demand might be. In other words we guessed the demand at a price of $p = 0$. Converted to units of AF/yr, this gives us our estimate of a (column "Max Use a" in Table 3). From (2) our estimate of b is:

$$b = \frac{(a - q^I)}{p^I} \ (3)$$

As a check on this, we can calculate the cutoff price, p^*, at which demand would fall to zero. This satisfies:

$$0 = a - bp^* \ or \ p^* = \frac{a}{b} \ (4)$$

For the cities with excess demand beyond their new reduced Tier 1 limits, the residual demand for auctioned water, denoted q^R is given by:

$$q^R = (q - q^L) = (a - q^L) - bp = a^R - bp \ (5)$$

As the slope b stays the same and the intercept of the demand function on the horizontal axis is reduced from a to a^R(see the "New a" column on Table 3), the reduced demand corresponds to a parallel shift downward in the demand function. As a check, we can calculate the new cutoff price:

$$p^{**} = \frac{a^R}{b}$$

It is important to note that we do not use the cutoff prices in creating the reduced demand functions (see the "p^{**} " column on Table 3).

V) The Auction

The Metropolitan Water District of Southern California as previously mentioned in the course of this paper is essentially a cooperative, not a for profit, investor-owned business. The cooperative setting makes politically unpalatable the idea of charging different agencies different prices, making the Vickrey auction not a viable option. Therefore, we decided to set up a multi-unit uniform price auction, so that each agency ends up paying the same price.

In the auction that follows, Foothill, San Marino and Torrance are excluded as their unfilled demand is extremely low when compared to the bundle-units of water that the agencies bid for. For the sake of simplicity we assume that MWD comes up with a specific pricing policy targeted for these three agencies. Such a policy could definitely be assisted by the outcome of the auction. Therefore, the remaining member agencies that pass the new Tier 1 limits and then enter the auction are: Beverly Hills, Calleguas, Eastern, Las Virgenes, Los Angeles, Pasadena, San Diego CWA, Three Valleys and Western. For these member agencies we set up a two-stage uniform price auction. For the first 31,000 acre feet, which correspond to the sum of the unfilled demands of the agencies that have low demands for water at the previous Tier 2 rate, all agencies bid for units of 1000 acre feet. The remaining 465,000 acre feet that correspond to the difference between the total unfilled demand and the 31,000 acre feet just mentioned above, are instead sold in units of 25,000 acre feet.

In order to run the auction model, we defined bid vectors for the agencies involved in the auction by using the demand functions we devised in the previous section. We proceeded as follows. For the first 1000 unit, we plugged in $q = 500$ into $p = (a - q)/b$ for each agency (using New “a” and “b” from Table 3). Then, we multiplied that value by 1000 to get an estimate of each agency’s willingness to pay for the first “1000 acre-feet” unit. We applied the same method to the following “1000 acre-feet” units. Then, once the bids for the first 31,000 acre feet were collected, we applied the same reasoning for the remaining water to be allocated in “25000 acre-feet” units. The two tables, Table 4 and Table 5 in the Appendix, report the bid vectors that were found. Then, each agency’s k-bid vector was compared to the k-vector of competing bids, following the discussion of uniform-price auction in chapter 12 of “Auction Theory”. Table 6 and Table 7 depict all the vectors that needed to be checked in order to correctly allocate the water. Thus, for an agency to win exactly one unit it was the case that the highest bid was higher than the lowest competing bid and that the second highest bid was lower than the second lowest competing bid. In Table 6 and Table 7 the winning bids with the relative competing bids are underlined in yellow. The market-clearing price is then set at the value of the highest losing bid. Comparing the agencies' vectors and the corresponding competing vectors, it was found that in the first stage Eastern buys 20 units that correspond to 20,000 acre feet, Western buys 11 units that correspond to 11,000 acre feet and all the other agencies get 0 units. The market-clearing price, or highest losing bid, is then $1,464,338 per 1000 acre-feet (in red in Table 6). In the second stage, it was found that Eastern buys 3 units, Los Angeles 6 units, San Diego CWA 6 units and Western gets 2 units, which respectively correspond to 75,000, 150,000, 150,000 and 50,000 acre feet. The market clearing price, or highest losing bid, is then $27,109,821 (in red in Table 7).

V) Conclusion

The main conclusion of this paper is that a multi-unit uniform price auction does reallocate water to the agencies that value it the most. In the first stage all but two agencies get cut off from the "Tier 2 water", while five agencies get cut off in the second stage. Furthermore, this thesis' finds that in the first stage the water is priced at $p = \$1464$ per acre-foot while in the second stage it is priced at $p = \$1084$ per acre-foot. This means that in both stages the price increased by a lot in comparison to the 2014 Tier 2 price of $743. In other words, not only was the water reallocated to the member agencies that valued it the most, but the price of the water itself increased as a better representation of the actual high value that water has to the member agencies. Therefore, lowering the Tier 1 limit for each agency and substituting the fixed Tier 2 rate with a uniform-price auction for the unfilled demands seems indeed to be an efficient way of reallocating water.

The outcome of the auction run in this paper is not flawless. Indeed, the agencies' demand functions are estimated with a theoretical model that included some fair guesses. Also, the fact that such demand functions represent the inverse of the corresponding bid vectors is an underlying assumption. This would be the case if “bid shading” or “demand reduction” were not in place and in the literature review we saw how uniform auctions tend to display bid shading. Nevertheless, we can still expect uniform price auctioning to have a very positive impact in terms of water allocation given the extremely positive impact that it has in this paper.

The main value of this thesis is that it is one of the first in its kind. Auctions have been a topic of discussion in the water literature and they have been applied or discussed in a multitude of settings. Nevertheless, they have never been applied as a direct allocation method from a water purveyor to its member agencies. The current drought in California calls for a better allocation of water that is truly representative of the value that it has for its buyers. Thus, this senior thesis wants to draw attention to auctions as a possible viable means in the better water allocation that is a pivotal step in reducing the water consumed by the State of California.

Appendix

Table 1

Member Agency	Total Local Production	Total Local Use	MWD Direct Deliveries	MWD Indirect Deliveries	MWD Total Deliveries	Total Water Use	MWD Direct Deliveries as % of Total Use
Anaheim	53,769	53,769	13,635		13,635	67,404	20%
Beverly Hills	747	747	11,632		11,632	12,379	94%
Burbank	13,330	13,330	8,817	7000	15,817	22,147	40%
Calleguas	39,479	49,716	113,856		113,856	163,571	70%
Central Basin	196,456	219,828	33,951		33,951	253,778	13%
Compton	7,858	7,858	44		44	7,902	1%
Eastern	129,117	129,117	106,193		106,193	235,309	45%
Foothill	9,674	9,674	9,795		9,795	19,469	50%
Fullerton	21,279	21,279	8,776		8,776	30,055	29%
Glendale	10,196	10,196	20,341		20,341	30,537	67%
Inland Empire	236,947	236,947	67,038	796	67,833	303,984	22%
Las Virgenes	5,001	5,145	22,360		22,360	27,505	81%
Long Beach	32,576	32,576	36,340		36,340	68,916	53%
Los Angeles	148,906	149,777	447,113		447,113	596,890	75%
MWDOC	350,188	364,463	191,518	50,701	242,218	555,981	34%
Pasadena	10,896	10,883	23,097		23,097	33,979	68%
SD CWA	89,049	89,049	545,659		545,659	634,708	86%
San Fernando	3,108	3,108	61		61	3,170	2%
San Marino	4,418	4,418	1,583		1,583	6,001	26%
Santa Ana	28,259	28,259	10,343		10,343	38,602	27%
Santa Monica	8,621	8,621	5,900		5,900	14,521	41%
Three Valleys	58,291	58,291	67,962	3,110	71,072	126,253	54%
Torrance	4,623	11,109	17,210		17,210	28,318	61%
Upper San Gabriel	211,736	171,174	3,490	31,289	34,779	174,665	2%
West Basin	65,460	63,508	120,915		120,915	184,422	66%
Western	190,584	190,584	75,910		75,910	266,494	28%

Table 2

	2014	2013	2012	2011	2010
Tier 1	593	593	560	527	484
Tier 2	743	743	686	652	594
System Access	243	223	217	204	154
Water Stewardship	41	41	43	41	41
System Power Rate	161	189	136	127	119
Treatment Surcharge	297	254	234	217	217
Capacity Charge	8,600	6,400	7,400	7,200	7,200
Readiness-to-Serve	166	142	146	125	114

Table 3

Member Agency	MWD Direct Deliveries	Total Use	% MWD	Tier 2	Marginal Price	Reduced Limit	B-0.8*L	Unfilled demand	Population	Use	Max Use	Max Use	Max Use "a"	"b"	Cutoff p*	New "a"	p**
	(B)	(A+B)	B/(A+B)	(B-L)	p'	0.8*L	M	Max (M,0)		gpcd	gpcd	mg/d	AF				
Anaheim	13,635	67,404	20.2%		593	19,551	-5,916										
Beverly Hills	11,632	12,379	94.0%		593	10,704	928	928	42,000	263	450	18.9	21,187	14.9	1426	10,483	706
Burbank	8,817	22,147	39.8%		593	13,421	-4,604										
Calleguas	113,856	163,572	69.6%	3,608	743	88,198	25,658	25,658	620,000	236	350	217	243,257	107.2	2268	155,059	1446
Central Basin	33,951	253,779	13.4%		593	86,124	-52,173										
Compton	44	7,902	0.6%		593	2,698	-2,654										
Eastern	106,193	235,310	45.1%	13,768	743	73,940	32,253	32,253	755,000	278	450	339.75	380,860	195.9	1944	306,920	1567
Foothill	9,795	19,469	50.3%		593	9,418	377	377	88,000	198	400	35.2	39,459	33.7	1171	30,041	891
Fullerton	8,776	30,055	29.2%		593	9,039	-263										
Glendale	20,341	30,537	66.6%		593	20,978	-637										
Inland Empire	67,038	303,985	22.1%		593	74,626	-7,588										
Las Virgenes	22,360	27,505	81.3%	1,661	743	16,559	5,801	5,801	75,384	326	500	37.692	42,253	19.8	2129	25,694	1294
Long Beach	36,340	68,916	52.7%		593	41,443	-5,103										
Los Angeles	447,113	596,890	74.9%	111,450	743	268,530	178,583	178,583	3,935,257	135	250	983.81425	1,102,856	681.0	1620	834,325	1225
MWDOC	191,518	555,981	34.4%		593	224,474	-32,956										
Pasadena	23,097	33,979	68.0%	1,917	743	16,944	6,153	6,153	165,740	183	300	49.722	55,738	29.3	1903	38,794	1325
San Diego CWA	545,659	634,708	86.0%	152,117	743	314,834	230,825	230,825	3,100,000	183	300	930	1,042,530	548.9	1899	727,696	1326
San Fernando	61	3,169	1.9%		593	503	-442										
San Marino	1,583	6,001	26.4%	384	743	959	624	624	13,250	404	600	7.95	8,912	3.9	2275	7,953	2030
Santa Ana	10,343	38,602	26.8%		593	15,694	-5,351										
Santa Monica	5,900	14,521	40.6%		593	8,888	-2,988										
Three Valleys	67,962	126,253	53.8%		593	59,938	8,024	8,024	525,000	215	400	210	235,410	184.1	1279	175,472	953
Torrance	17,210	28,319	60.8%		593	16,774	436	436	118,938	213	400	47.5752	53,332	42.2	1264	36,558	867
Upper San Gabriel	3,490	174,664	2.0%		593	53,782	-50,292										
West Basin	120,915	184,423	65.6%		593	126,018	-5,103										
Western	75,910	266,494	28.5%		593	68,088	7,822	7,822	878,000	271	400	351.2	393,695	214.5	1835	325,607	1518
TOTAL	1,963,539	3,906,964	50.3%	284,905		1,642,126		497,483					3,619,489				

Table 4

	Beverly Hills	Calleguas	Eastern	Las Virgenes	Los Angeles	Pasadena	San Diego CWA	Three Valleys	Western
500	672107.9599	1441137.476	1564206.563	1269265.964	1224454.864	1307607.777	1324859.682	950540.5865	1515619.111
1500	604782.0366	1431813.262	1559101.78	1218885.336	1222986.385	1273461.555	1323037.809	945108.0444	1510957.205
2500	537456.1133	1422489.048	1553996.996	1168504.708	1221517.906	1239315.333	1321215.935	939675.5023	1506295.299
3500	470130.1899	1413164.834	1548892.212	1118124.08	1220049.427	1205169.111	1319394.062	934242.9601	1501633.393
4500	402804.2666	1403840.62	1543787.428	1067743.452	1218580.948	1171022.89	1317572.189	928810.418	1496971.488
5500	335478.3433	1394516.406	1538682.645	1017362.824	1217112.47	1136876.668	1315750.316	923377.8759	1492309.582
6500	268152.42	1385192.192	1533577.861	966982.196	1215643.991	1102730.446	1313928.442	917945.3338	1487647.676
7500	200826.4967	1375867.978	1528473.077	916601.568	1214175.512	1068584.224	1312106.569	912512.7917	1482985.771
8500	133500.5733	1366543.764	1523368.293	866220.94	1212707.033	1034438.003	1310284.696	907080.2495	1478323.865
9500	66174.65003	1357219.549	1518263.51	815840.312	1211238.555	1000291.781	1308462.823	901647.7074	1473661.959
10500	0	1347895.335	1513158.726	765459.684	1209770.076	966145.5591	1306640.949	896215.1653	1469000.053
11500	0	1338571.121	1508053.942	715079.056	1208301.597	931999.3374	1304819.076	890782.6232	1464338.148
12500	0	1329246.907	1502949.158	664698.4279	1206833.118	897853.1156	1302997.203	885350.0811	1459676.242
13500	0	1319922.693	1497844.375	614317.7999	1205364.639	863706.8939	1301175.329	879917.539	1455014.336
14500	0	1310598.479	1492739.591	563937.1719	1203896.161	829560.6721	1299353.456	874484.9968	1450352.431
15500	0	1301274.265	1487634.807	513556.5439	1202427.682	795414.4504	1297531.583	869052.4547	1445690.525
16500	0	1291950.051	1482530.023	463175.9159	1200959.203	761268.2286	1295709.71	863619.9126	1441028.619
17500	0	1282625.837	1477425.239	412795.2878	1199490.724	727122.0069	1293887.836	858187.3705	1436366.714
18500	0	1273301.623	1472320.456	362414.6598	1198022.246	692975.7851	1292065.963	852754.8284	1431704.808
19500	0	1263977.409	1467215.672	312034.0318	1196553.767	658829.5634	1290244.09	847322.2862	1427042.902
20500	0	1254653.194	1462110.888	261653.4038	1195085.288	624683.3416	1288422.217	841889.7441	1422380.996
21500	0	1245328.98	1457006.104	211272.7758	1193616.809	590537.1199	1286600.343	836457.202	1417719.091
22500	0	1236004.766	1451901.321	160892.1478	1192148.331	556390.8981	1284778.47	831024.6599	1413057.185
23500	0	1226680.552	1446796.537	110511.5197	1190679.852	522244.6764	1282956.597	825592.1178	1408395.279
24500	0	1217356.338	1441691.753	60130.89172	1189211.373	488098.4546	1281134.723	820159.5757	1403733.374
25500	0	1208032.124	1436586.969	9750.263702	1187742.894	453952.2329	1279312.85	814727.0335	1399071.468
26500	0	1198707.91	1431482.186	0	1186274.415	419806.0111	1277490.977	809294.4914	1394409.562
27500	0	1189383.696	1426377.402	0	1184805.937	385659.7894	1275669.104	803861.9493	1389747.656
28500	0	1180059.482	1421272.618	0	1183337.458	351513.5676	1273847.23	798429.4072	1385085.751
29500	0	1170735.268	1416167.834	0	1181868.979	317367.3459	1272025.357	792996.8651	1380423.845
30500	0	1161411.054	1411063.051	0	1180400.5	283221.1241	1270203.484	787564.3229	1375761.939

Table 5

	Beverly Hills	Calleguas	Eastern	Las Virgenes	Los Angeles	Pasadena	San Diego CWA	Three Valleys	Western
43000	0	26121459.43	33681331.34	0	29051112.89	0	31185751.7	17991438.66	32937202.95
68000	0	20293825.63	30490841.49	0	28133313.66	0	30047080.91	14596099.84	30023511.89
93000	0	14466191.82	27300351.64	0	27215514.42	0	28908410.12	11200761.01	27109820.82
118000	0	8638558.01	24109861.79	0	26297715.19	0	27769739.32	7805422.19	24196129.75
143000	0	2810924.202	20919371.94	0	25379915.96	0	26631068.53	4410083.366	21282438.69
168000	0	0	17728882.09	0	24462116.72	0	25492397.74	1014744.542	18368747.62
193000	0	0	14538392.24	0	23544317.49	0	24353726.94	0	15455056.56
218000	0	0	11347902.39	0	22626518.25	0	23215056.15	0	12541365.49
243000	0	0	8157412.543	0	21708719.02	0	22076385.36	0	9627674.424
268000	0	0	4966922.693	0	20790919.79	0	20937714.57	0	6713983.359
293000	0	0	1776432.843	0	19873120.55	0	19799043.77	0	3800292.293
318000	0	0	0	0	18955321.32	0	18660372.98	0	886601.227
343000	0	0	0	0	18037522.08	0	17521702.19	0	0
368000	0	0	0	0	17119722.85	0	16383031.4	0	0
393000	0	0	0	0	16201923.62	0	15244360.6	0	0
418000	0	0	0	0	15284124.38	0	14105689.81	0	0
443000	0	0	0	0	14366325.15	0	12967019.02	0	0
468000	0	0	0	0	13448525.91	0	11828348.23	0	0
493000	0	0	0	0	12530726.68	0	10689677.43	0	0

Table 6

Eastern	Competition	Calleguas	Competition	Western	Competition
1564206.563	1399071.468	1441137.476	1467215.672	1515619.111	1422489.048
1559101.78	1403733.374	1431813.262	1469000.053	1510957.205	1426377.402
1553996.996	1403840.62	1422489.048	1472320.456	1506295.299	1431482.186
1548892.212	1408395.279	1413164.834	1473661.959	1501633.393	1431813.262
1543787.428	1413057.185	1403840.62	1477425.239	1496971.488	1436586.969
1538682.645	1413164.834	1394516.406	1478323.865	1492309.582	1441137.476
1533577.861	1417719.091	1385192.192	1482530.023	1487647.676	1441691.753
1528473.077	1422380.996	1375867.978	1482985.771	1482985.771	1446796.537
1523368.293	1422489.048	1366543.764	1487634.807	1478323.865	1451901.321
1518263.51	1427042.902	1357219.549	1487647.676	1473661.959	1457006.104
1513158.726	1431704.808	1347895.335	1492309.582	1469000.053	1462110.888
1508053.942	1431813.262	1338571.121	1492739.591	1464338.148	1467215.672
1502949.158	1436366.714	1329246.907	1496971.488	1459676.242	1472320.456
1497844.375	1441028.619	1319922.693	1497844.375	1455014.336	1477425.239
1492739.591	1441137.476	1310598.479	1501633.393	1450352.431	1482530.023
1487634.807	1445690.525	1301274.265	1502949.158	1445690.525	1487634.807
1482530.023	1450352.431	1291950.051	1506295.299	1441028.619	1492739.591
1477425.239	1455014.336	1282625.837	1508053.942	1436366.714	1497844.375
1472320.456	1459676.242	1273301.623	1510957.205	1431704.808	1502949.158
1467215.672	1464338.148	1263977.409	1513158.726	1427042.902	1508053.942
1462110.888	1469000.053	1254653.194	1515619.111	1422380.996	1513158.726
1457006.104	1473661.959	1245328.98	1518263.51	1417719.091	1518263.51
1451901.321	1478323.865	1236004.766	1523368.293	1413057.185	1523368.293
1446796.537	1482985.771	1226680.552	1528473.077	1408395.279	1528473.077
1441691.753	1487647.676	1217356.338	1533577.861	1403733.374	1533577.861
1436586.969	1492309.582	1208032.124	1538682.645	1399071.468	1538682.645
1431482.186	1496971.488	1198707.91	1543787.428	1394409.562	1543787.428
1426377.402	1501633.393	1189383.696	1548892.212	1389747.656	1548892.212
1421272.618	1506295.299	1180059.482	1553996.996	1385085.751	1553996.996
1416167.834	1510957.205	1170735.268	1559101.78	1380423.845	1559101.78
1411063.051	1515619.111	1161411.054	1564206.563	1375761.939	1564206.563

Table 7

Calleguas	Competition	Eastern	Competition	Los Angeles	Competition	San Diego CWA	Competition	Western	Competition
26121459.43	27300351.64	33681331.34	26631068.53	29051112.89	21282438.69	31185751.7	21282438.69	32937202.95	26297715.19
20293825.63	30023511.89	30490841.49	27109820.82	28133313.66	22076385.36	30047080.91	21708719.02	30023511.89	26631068.53
14466191.82	30490841.49	27300351.64	27215514.42	27215514.42	23215056.15	28908410.12	22626518.25	27109820.82	27215514.42
8638558.01	32937202.95	24109861.79	27769739.32	26297715.19	24109861.79	27769739.32	23544317.49	24196129.75	27300351.64
2810924.202	33681331.34	20919371.94	28133313.66	25379915.96	24196129.75	26631068.53	24109861.79	21282438.69	27769739.32
		17728882.09	28908410.12	24462116.72	24353726.94	25492397.74	24196129.75	18368747.62	28133313.66
		14538392.24	29051112.89	23544317.49	25492397.74	24353726.94	24462116.72	15455056.56	28908410.12
		11347902.39	30023511.89	22626518.25	26121459.43	23215056.15	25379915.96	12541365.49	29051112.89
		8157412.543	30047080.91	21708719.02	26631068.53	22076385.36	26121459.43	9627674.424	30047080.91
		4966922.693	31185751.7	20790919.79	27109820.82	20937714.57	26297715.19	6713983.359	30490841.49
		1776432.843	32937202.95	19873120.55	27300351.64	19799043.77	27109820.82	3800292.293	31185751.7
				18955321.32	27769739.32	18660372.98	27215514.42	886601.227	33681331.34
				18037522.08	28908410.12	17521702.19	27300351.64		
				17119722.85	30023511.89	16383031.4	28133313.66		
				16201923.62	30047080.91	15244360.6	29051112.89		
				15284124.38	30490841.49	14105689.81	30023511.89		
				14366325.15	31185751.7	12967019.02	30490841.49		
				13448525.91	32937202.95	11828348.23	32937202.95		
				12530726.68	33681331.34	10689677.43	33681331.34		

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