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Auctions for PURPA Purchases: A Simulation Study

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Abstract
Competition was introduced into the electric utility industry with the passage of the Public Utilities Regulatory Policy Act (PURPA) of 1978. Increasing interest has appeared in structuring the PURPA purchase market into an auction system. This paper addresses the design issues associated with setting up such markets and introduces a simulation model to study them. The simulation analysis is guided by theoretical issues such as the alleged inefficiency of first-price auctions. We find that efficiency concerns raised about first-price auctions turn out to be less important than simple theoretical concerns would suggest.

Competition was explicitly introduced in the electric utility industry with the passage of the Public Utilities Regulatory Policy Act (PURPA) of 1978. The act opened the bulk power market to private unregulated producers by requiring utilities to purchase their output under avoided cost tariffs. PURPA also allowed for binding long term contracts. Implementation of PURPA has been studied by Devine, et al. (1987, 85-101). A common experience of states implementing PURPA was to find substantially greater response to long run contract offers than to short-term reviseable tariffs. (See for example New Jersey Board of Public Utilities (1987).) In some cases, the amount of power offered under long term contracts substantiallyexceeded perceived requirements. Increasing interest has appeared at both the state and federal levels in structuring the PURPA purchase market into an auction system. This interest arises from several sources,including dissatisfaction with the administrative process of posting avoided cost prices and a perception that the increasing competitiveness of private power production would create welfare and efficiency benefits (Pfeffer, Lindsay and Associates 1986). Auctions provide a means of rationing the power requirement in the

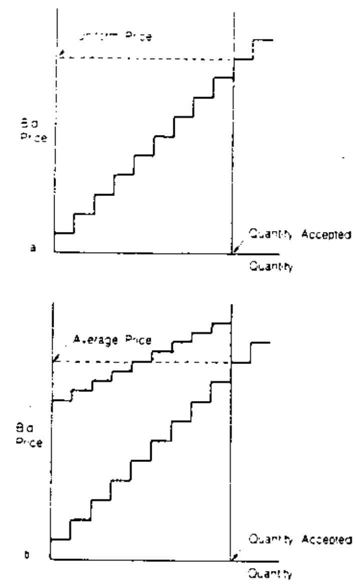

Figure 1. (a) Second-price auction. (b) First-price auction with consistent expectations.

upper panel illustrates the case of many bidders offering equal quantities at uniformly increasing cost. The bid price of the first rejected bidder determines the uniform price that all winners will receive. The lower panel reproduces the picture from the upper panel and adds to it a representation of the first-price situation. In this case, bidders no longer bid their cost, but a price which estimates the competitive outcome. Thus bids in this case are generally higher than in the Vickrey case. Some of the winning bids in the first-price auction will be higher than the uniform price and some will be lower. On the average, however, they can be expected to be the same. This is shown on the lower panel by the equal shaded areas. In his original paper, Vickrey proved a version of the revenue equivalence theorem, which has since been generalized several times. (See, for example, Myerson (1981, 58-73).)

The theoretical advantages of the Vickrey auction have been discussed in the PURPA context. The California Public Utilities Commission (CPUC) (1986) adopted this format for future PURPA auctions, although it is not anticipated that these will be held for at least several years. This decision was influenced by arguments pointing out the truth revealing properties of Vickrey auctions made by representatives of the Southern California Edison Company (Jurewitz 1986; Vail 1986). Analysis of this issue by the Staff of the New York Department of Public Service (1987) is more agnostic, but does recognize the theoretical advantages of the second-price mechanism.

Examination of actual auction practice reveals very few Vickrey type procedures. While many explanations of this rarity are possible, there is one fundamental practical problem which bars their real world implementation. There are strong economic incentives for bidders in a PURPA auction, or any other complicated sale of a scarce entitlement, not to reveal their costs. This incentive involves the economic context in which successful bidders will have subsequent negotiations with third parties. PURPA suppliers, for example, may have to negotiate with equipment suppliers, permitting authorities, financial institutions,

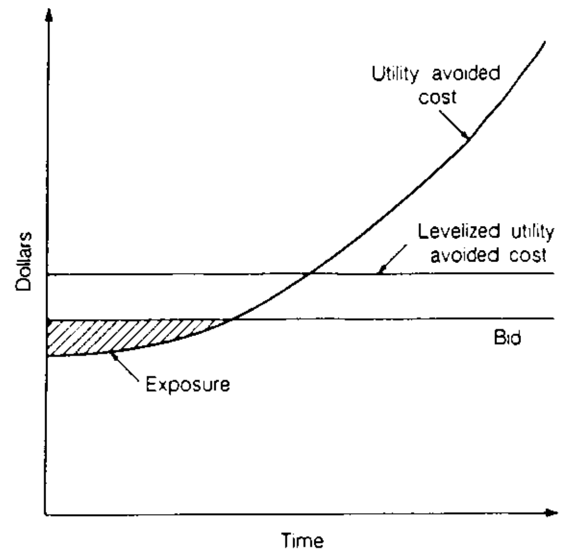

Figure 2. Abandonment exposure due to "front-loading."

the offers to sell power which we are considering are long-term, they involve a projection of payments over time. The proposed time stream may involve payments in the early years of a project's life that exceed estimated avoided cost value. Projected over the life of the contract, the present-value of a bid may still be less than estimated avoided cost, even with a front loading. The evaluation problem in such cases is that front loading imposes a risk on ratepayers that is absent from bids which do not have this feature. Figure 2 illustrates this problem in a simple case in which the bidder offers a flat price that is less than the present-value equivalent of the avoided cost (levelized avoided cost), but is front loaded. The hatched area represents the risk exposure of the utility in the event of premature project abandonment before the benefits of the low bid price in later years are realized.

There are two possible ways to treat front loading. First, it may be ruled out completely. This is the approach taken by the California PUC (1986). A second approach is to develop weighting factors that penalize bids with front loading compared to otherwise equivalent bids without front loading. This approach has been taken in Maine and Massachusetts. The implementation of a weighting factor approach is subjective to some degree. The quantification of the risk exposure and the development of a price for risk are imprecise. The methods used by Boston Edison (1986) and Western Massachusetts Electric (1986) attempt to differentiate bids by the degree of exposure. This is an improvement over methods that just use a simple qualitative differentiation.

A second class of non-price factors that is important in bid evaluation concerns operational characteristics. One of these which has received considerable attention is dispatchability. The value of power varies considerably at different times depending on the supply/demand balance. Utilities that purchase from PURPA producers under the statutory obligation have very limited freedom to curtail output at times of low value. In some cases, the PURPA purchase obligation has caused operational problems; more frequently it has

The specification of a quantity limit for power auctions serves to provide a means of limiting the acceptance of offers. The absence of limits has been a problem in some PURPA implementation situations. But the quantity limit is usually not intended to be a "hard" constraint in the sense that dire results would follow from some violation of the limit. Forecasting power requirements is an imperfect art, not all winners can be expected to actually deliver, and power beyond a given level will still have some economic value, albeit diminishing to some degree.

Given these circumstances, three means of mitigating the effect of "lumpy" capacity bids have been suggested. First, the utility may specify a tolerance limit. A requirement for capacity can be specified in terms of an acceptable range, say the original limit plus 10%. A second approach is to provide an upper bound for valuing quantities beyond the specified limit. The avoided cost for excess quantities would be a declining function of quantity, due to diminishing returns. A third approach involves offering the marginal bidder the opportunity to downsize his project so as to meet quantity constraints. These three approaches can interact with one another in a variety of ways depending on the order in which they are applied. It is probably most reasonable to use them in the order listed.

Because lumpiness problems can be expected to be endemic in PURPA auctions, it is important to determine in advance how they will be dealt with in the acceptance process. Such administrative details are an important part of establishing credibility and confidence in the process and its results among all participants.

A Simulation Model: The General Structure

Simulation models are useful for studying the behavior of PURPA auction markets. Simulations have also been used to study experimentallyauction mechanisms for natural gas networks (McCabe, Rassenti, and Smith, to appear). This section describes the model we have developed. Data requirements and sources are summarized next, followed by our results. Numerous simplifications of the real process are necessary for a tractable analysis. These are identified in this discussion.

Bidder Behavior

We represent bidders by cost functions and expectations. The cost function for a bidder is only a representation of his first year cost possibilities depending upon the choice of capacity he makes. That cost function indicates what his average and marginal cost of power would be if he chose capacity of one size or another. We ignore the time dimension and issues such as front-loading that are related to long term price trajectories. All bidders are assumed to be cogenerators using natural gas fired turbines. We represent the technological diversity of the bidders by different cogeneration opportunities; i.e., larger or smaller steam loads. The next section gives details.

Expectations play a crucial role. First, they determine the bidder's choice of capacity. There is a substantial range of capacity choices that a given cogeneration site can support. The bidder's expectation of the price that he can get affects his choice of capacity. We assume capacity to be chosen at that level where the price estimate intersects the marginal cost curve. Figure 3 shows the sensitivity of capacity to price expectations. This figure is a cost function representing mid-1990s conditions for one of our typical bidders. For a price expected profits. On a given bid of B, the expected profit is the difference between the bid and the bidder's average cost, AC, times the probability of winning. We assume that the uncertainty around the bidder's estimate of the cut-off price is distributed normally. We denote the cumulative normal distribution for a variate x with mean M and standard deviation SD by $N(x, M, SD)$. The probability of winning with a bid B given an expected cut-off price of M and a standard deviation SD is given by the complement of the cumulative normal distribution up to B; i.e.,

$$\text{Probability of Winning with } B = 1 - N(B, M, SD).$$

Figure 4 illustrates this. Using this notation, the expected profit, $E(B)$, on a bid B can be written as

$$E = (B - AC)\,(1 - N(B, M, SD)).$$

The profit maximizing bid is found by setting $dE/dB = 0$ and solving for B. This general approach was first described by Friedman (1956, 104-112).

Acceptance Rules

A particular simulation consists of specifying cost curves for active bidders, expectations as indicated above for each bidder, and a quantity limit for acceptance. To provide for the greatest flexibility, we allow bidders to have different expectations and variances about the cut-off price. To calculate the actual cut-off price in a given situation, we must specify the acceptance rule. To illustrate the variability of results due to the difference among acceptance rules, we work with five different rules. Rule 1 requires that the last bid be rejected if the sum of the quantities offered including that bid exceed the quantity limit. Rule 2 allows the last bid to be accepted if it fills any unfilled part of the quantity requirement that has not been filled by previously accepted bids. Rule 3 treats the capacity limit as absolutely binding (as in Rule 1), but allows for searching past the rejected bidders to fill up the auction allotment (this is not allowed under Rule 1). Rule 3 places an implicit value of zero on quantities beyond the specified limit. Rule 4 relaxes this by placing an avoided cost value on excess quantities. Under Rule 4, only the first marginal bidder has an opportunity to be accepted with excess quantities. If this bidder is rejected, the auction ends. Finally, Rule 5 is similar to Rule 4 with regard to valuing excess quantities, but the auction does not end if a marginal bidder is rejected. Evaluation under Rule 5 proceeds until a final bidder has been accepted or they have all been considered.

Evaluation Measures

To evaluate a particular outcome, it is useful to measure the degree to which expectations are consistent with what actually occurred. We calculate a quantity we call the "surprise" for this purpose. The surprise for a given bidder is the difference between the actual auction cut-off price and the bidder's estimate of the mean cut-off price divided by the bidders estimate of the standard deviation of the cut-off price distribution. This expresses surprise in units of the bidder's own uncertainty. With this normalization, we can then characterize the average surprise of the auction as a whole.

We are also interested in the difference between the minimum social cost of power and the simulated auction outcome. We develop a number of indices to characterize and analyze

Data Characterization

Two kinds of data are necessary to run the simulations. First, the utility avoided cost structure must be specified. This will set an upper bound on acceptable bids, determine the quantity to be purchased, and set a value on quantities offered beyond the auction limit. The second kind of data necessary are cost functions characterizing bidders. These are ultimately required only in the form of marginal and average cost curves such as that illustrated in figure 3. In practice, these curves should be linked to realistic expectations concerning the cost characteristics of potential bidders. We discuss our approach to each kind of data. In all cases, our methods derive from conditions assumed to represent the power market in Southern California in the mid-1990s and the regulatory practice of the California Public Utilities Commission.

Avoided Cost Structure

The CPUC has specified in fairly elaborate detail the procedure for determining when new long term PURPA contracts will be made available and what will be their maximum price (i.e., the "avoided cost"). The basic method adopted by the CPUC is the "proxy plant" approach to determining avoided cost. This method identifies the avoided cost in the long run with the total costs of "deferrable resources" that utilities might construct. The CPUC has outlined a process to identify such resources and determine when they are needed. The date when this occurs then defines the time for which PURPA contracts can be auctioned, and the capacity of needed deferrable resources determines the amount of capacity for which bids will be sought.

For our purposes, we have relied on information made available in public hearings by the Southern California Edison Company (SCE) implementing these procedures. Our interpretation of the CPUC tests differs slightly from that offered by the utility. The primary difference involves the interaction between the prices paid to existing PURPA producers and the addition of new resources. We argue that the latter reduces the former under current rules and, therefore, increases the value of new resources. While details at this level are unimportant for the simulation, they are important for implementation of these procedures in practice.

The conclusion of our analysis of SCE is that there is a need for 500 MW of new baseload capacity in 1996. Its value is approximately 12 cents/kWh in that year. The next 200 MW of capacity is worth approximately 8 cents/kWh. The main difference being that the additional increment has only energy value and not capacity value. Details of the estimation procedure are contained in Rothkopf et al. (1987).

Representative Bidders' Cost

We assume that the PURPA market in the mid-1990s in Southern California will be dominated by natural gas-fired cogeneration. This assumption is essentially a projection of the current trends. To estimate the cost function of gas-fired cogenerators we need some information about the costs and efficiency of the equipment used in these applications and the steam loads available for these applications. The economics of cogeneration depends on the ability to make productive use of waste heat from power production (Joskow and Jones 1983, 1-22). Our set of representative bidders is differentiated chiefly along this

Table 1. QF Cost Function - 1996 (Gas Turbines)

Capacity (MW)	175	150	125	100	75	50	25	5
Capital Cost ($M)	186	159	138	115	91	66	38	10
$/KW	1062	1062	1101	1151	1218	1320	1514	2082
Annual Charge Rate	0.17	0.16	0.15	0.15	0.15	0.15	0.15	0.15
Annual Charge ($M)	32	25	21	17	14	10	6	2
Hours	6750	6750	6750	6750	6750	6750	6750	6750
Heat Rate (kJ/kWh)	11078	11078	11078	11078	11078	11078	11078	12660
Fuel Cost ($/kJ)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Annual Fuel Bill ($M)	98	84	70	56	42	28	14	3
Steam Load (MJ/hr)	158	158	158	158	158	137	84	21
Net Electric Heat Rate	10173	10023	9812	9495	8968	8335	7702	8440
Value of Steam ($M)	10	10	10	10	10	9	5	1
On-Site Electricity								
Credit Load (MW)	10	10	10	10	10	10	10	10
Value @ $12/MWh	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Unit Cost ($/kWh)	0.1005	0.0974	0.0946	0.0925	0.0887	0.0842	0.0802	0.0776
Marginal Cost ($/kWh)	0.1191	0.1117	0.1030	0.1040	0.0976	0.0882	0.0809	

Table 2. Summary of Bidder Characteristics and Auction Results -Homogenous Expectations

Output Summary

Bidder	μ_i	σ_i	Q_i	AC_i	Bid	Surprise				
						Rule 1	Rule 2	Rule 3	Rule 4	Rule 5
a 0.095 0.01	0.095	0.010	75.	0.089	0.098	0.318	0.417	1.310	0.417	0.417
b 0.10 0.01	0.100	0.010	25.	0.102	0.108	-0.182	-0.083	0.810	-0.083	-0.083
c 0.10 0.01	0.100	0.010	125.	0.087	0.099	-0.182	-0.083	0.810	-0.083	-0.083
d 0.10 0.01	0.100	0.010	75.	0.099	0.106	-0.182	-0.083	0.810	-0.083	-0.083
e 0.10 0.01	0.100	0.010	325.	0.084	0.098	-0.182	-0.083	0.810	-0.083	-0.083

Auction Summary

	Cutoff price	Q_{tot}	R.M.S. surprise	Inefficiency						
				C_{tot}	C_{min}	C^{AC}_{min}	I_1	I_2	I_3	I_4
R1	0.098	400.	0.216	39.273	33.020	33.737	0.189	0.217	0.163	0.004
R2	0.099	525.	0.201	51.669	44.622	44.725	0.158	0.178	0.156	0.000
R3	0.108	500.	0.932	49.934	42.147	42.508	0.185	0.185	0.145	0.031
R4	0.099	525.	0.201	51.669	44.622	44.725	0.158	0.178	0.156	0.000
R5	0.099	525.	0.201	51.669	44.622	44.725	0.158	0.178	0.156	0.000

that most of the deviation from the social cost minimum (measured by index 1) is due to bidders' rent capture (index 3), turns out to be quite general.

The homogeneous expectations shown in table 2 cannot be expected to occur routinely. More interesting results appear when bidders have substantial differences in their views of the competition. Table 3 shows a case of this kind. Here we neglect the role of the small inefficient bidders, (b) and (d), and concentrate on the interactions of bidders who have costs which are relatively close. We also include two of the large type (e) bidders to examine more closely what happens when projects are large relative to the quantity to be purchased.

The two type (e) bidders have diametrically opposite expectations. One is a pessimist. He expects a very low cut-off price of 8 cents/kWh. This causes him to choose a relatively low capacity of 250 MW. Even at this size, however, his average costs are above his expectation of the cut off price. Thus to make a profitable bid he must bid above his expected value and therefore assume a low probability of winning. The outcome in all cases is quite different. The pessimist is the low bidder, he is accepted under every rule and has a very large value of surprise. Instead of facing tough competition from the other bidders, the pessimist is the competition with whom everyone else must cope.

The optimistic type (e) bidder offers a larger project at 325 MW. Although his costs are lower than the other two bidders, he is only accepted under Rule 2. In all other cases, his capacity offer is too large and his bid too high to be acceptable. This is true even under rules that provide an avoided cost value for his "excess" quantities. The presence of two large bidders makes the lumpiness problem worse than the situations illustrated in table 2. The variation in quantity accepted under the different rules is much larger in table 3 than in table 2. The variation in cut-off price is considerably less.

The competitive situation represented in table 3 results in a generally smaller deviation between utility payments to bidders and the social cost minimum (index 1) than is seen in table 2. This result is probably due to the pessimism and resulting low bid of the first type (e) bidder. His mis-estimation also results in a generally higher level of surprise. The Vickrey type inefficiencies measured by index 4 occur more often in table 3, but are still of a generally low absolute value.

The pattern of simulation results seen in tables 2 and 3 is general across many variations of bidders and their expectations. The values for index 1, the deviation of utility cost from the social minimum, range from a low of about 10% to a maximum of 25%. The bulk of this deviation from the social cost minimum is due to rent capture by bidders (index 3). The value of index 4, our measure of Vickrey-type inefficiency, is always rather small; it seldom exceeds 4%. This simulation result is quite interesting because it tends to call into question the need for second-price or non-discriminatory auctions. In our discussion of auction theory, we summarized the theoretical real world limits on truth-revealing strategies. Our simulation results suggest a further reason why Vickrey's concern may not be too important for power auctions. We outline the situation briefly and illustrate diagramatically why the concern may be small in this case.

Significant inefficiencies can occur only if the bidders have large differences in price expectations and simultaneously large differences in costs. In this case, a low estimator can force out a low-cost producer who is a high estimator. This situation is relatively unlikely to occur because there is an equilibrating effect that links expectations and costs through capacity choice. The inefficient outcome occurs if a low cost producer bids too high to be accepted. This combination is unlikely because such a producerwould increase his capacity if he thought that the cut-off price would be high. The additional capacity has higher cost (since we assume the bidder is operating under increasing marginal cost). Thus, larger capacity raises the bidder's average cost. This means that even if he were rejected, the inefficiency of not selecting him is not too great because his cost is not too low any more. The tendency toward equilibrium occurs because it is inconsistent to expect a high cut-off price, but choose a low capacity, and therefore a low cost. This result follows from our representation of the bidder's choice of capacity given a cost curve.

It is incorrect to measure efficiency effects from bidder's cost curves. We can only measure these effects given choices of capacity based on price expectations. In fact, expectations can result in a bidder with a "low" cost curve offering a project that is sized with an average cost that is higher than that of a bidder with a "high" cost curve. All that is necessary is that the first bidder expect a substantially higher price than the second. Figure 6 gives a simple example of this phenomenon. Although the bidder indexed by 1 has a "low" cost curve, his price expectation P1 is so much higher than the expectation of bidder 2 that they end up with projects having the same average cost. If P2 were only slightly lower, then the average cost of bidder 2 would be less than that of bidder 1.

Conclusions

PURPA auctions are likely to become a feature of the electricity supply system. It is even possible that the auction format in general will play a larger role in utility supply expansion. The U.S. Federal Energy Regulatory Commission (FERC) (1988) is considering such possibilities. Under these circumstances it is useful to try to understand auction markets through the use of simulation models. Simulations are helpful if they are guided by

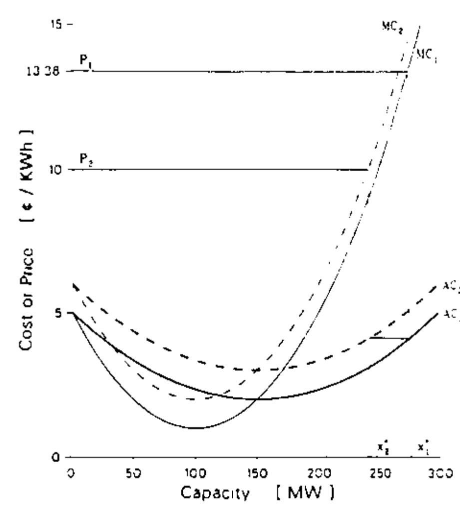

Figure 6. Effect of price expectations on capacity choice.

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