BIDDER COST REVELATION IN ELECTRIC POWER AUCTIONS

by

James Bushnell and Shmuel Oren

Memorandum No. UCB/ERL/IGCT M92/66

15 June 1992

ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley
94720

BIDDER COST REVELATION IN ELECTRIC POWER AUCTIONS

by

James Bushnell and Shmuel Oren

Memorandum No. UCB/ERL/IGCT M92/66

15 June 1992

ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley
94720

Bidder Cost Revelation in Electric Power Auctions

James Bushnell and Shmuel Oren
Dept. of Industrial Engineering
and Operations Research
University of California at Berkeley

1. Introduction

Over the last decade, the electric power industry has evolved from a collection of natural monopolies into an environment that is increasingly competitive. Competition has expanded primarily in the generation segment of the industry. In the early eighties, this was mostly due to producers of power who, as "Qualifying Facilities"(QFs), began selling wholesale to utilities that were required by law to buy the power at "avoided cost." More recently, the contracts offered to independent producers have been rationed through different forms of competitive bidding.

There has been much speculation about the effects the newly introduced competitive forces will have on both the cost and reliability of electric power (Summerton and Bradshaw, 1991). The hope of regulators is that competition will spur technological innovation and a more efficient use of capital. However, there is also some concern that competition will produce restrictions on the flow of information between utilities and power producers. A less open flow of information might lead to operational inefficiencies and lower reliability.

Typically, power sold by QFs has been of a "must-take" form. Purchasing utilities were not allowed to refuse purchase from a qualified supplier. As concern over the operational inefficiencies caused by must-take contracts has grown, utilities and regulators have placed increasing emphasis on incorporating some form of utility control into auctions for independently generated power.

We wish to examine auctions in which at least some operational control of the independent resource is granted to the purchasing utility. Such auctions

This research has been partially funded by National Science Foundation Grant IRI-8902813 and the University of California Universitywide Energy Research Group.

are increasingly common, having been adopted in New Jersey and New York, as well as forming an important component of upcoming auctions in California. At issue is whether the same level of operational efficiency achieved by a vertically integrated electric utility can be maintained in a system where some generation is acquired through competitive auctions. A utility that has full control over an independent resource will presumably operate it on the basis of the energy[1] price paid to that resource. It is therefore crucial for operational efficiency that the energy price paid reflect the true variable cost of the resource. In other words, it is desirable, for purposes of social efficiency, that bidders adopt a strategy of *truth-telling of variable costs.* We present conditions under which such strategies are feasible and discuss the implications for auction design that such conditions present.

Section two presents some background on auctions for electric generation and discusses the value of curtailability of a QF to a purchasing utility. In section three, we formulate a two dimensional auction model in order to analyze strategies involving truth-telling of energy costs. In section four we discuss two existing or proposed scoring systems. Section five gives an example of a second price auction using the scoring systems from section four.

2. Background

Under the Public Utilities Regulatory Policies Act (PURPA) of 1978 , utilities have been legally obligated to purchase power from producers who met certain criteria, namely QFs. In states such as California, where regulators created a favorable environment for QFs, the response was much larger than anticipated (Hulett, 1989). A glut of QF capacity has led to a rationing of independent generation through competitive bidding processes.

Competitive bidding represents a middle ground between strictly utility owned generation and the unlimited private supply initially offered in PURPA. It is hoped that the innovation and efficiency benefits of competition can be realized while simultaneously the quantity of capacity for which rate payers are obligated to pay is constrained.

The basic concept employed in all auctions is simple. A planning process supervised by regulators determines a desired capacity addition and a Request For Proposals (RFP) is issued. If the capacity of offered bids exceeds the desired capacity, bids are accepted in order of increasing "cost" until the desired capacity is reached. Many difficult policy questions have arisen in the process of trying to implement this concept in practice. Factors such as the discrete amounts of capacity offered by bidders made reaching exact capacity targets difficult. The financial viability of a winning bid's project affects the

[1]The terms variable cost and energy cost are equivalent for the purposes of this paper.

reliability of a system that is counting on the added capacity. The most contentious and difficult issue is how to define the cost or benefit of a project.

Beyond the prices bid by potential suppliers, many factors such as site location and transmission access directly affect the value of a project. In addition, Public Utilities Commissions are attempting to include "social" benefits such as fuel diversity and environmental factors into the selection process. These elements, which are not directly related to price, are generally referred to as *non-price factors.*

This paper focuses on another key non-price factor, concerning the level of operational control the purchasing utility is allowed to exercise over the new resource. Operational control takes many forms and names, but for the remainder of this paper we refer to operational control issues as *curtailability.* In it's simplest interpretation, curtailability (also known as dispatchability or operational control) is the right of the purchasing utility to refuse to purchase power from the QF in any given hour.

Several degrees of curtailability have been defined to capture the wide variation in the characteristics of size and warning time of the interrupted sale. At one extreme is fully automated dispatchability. A fully dispatchable generation unit is one that agrees to submit to remote utility control of its output levels. Such a unit may be shut down or have its output level varied with a warning time on the order of seconds. The other extreme is a unit which may not be shut down by the utility but may be "turned down" to some pre-specified minimum operating level. A warning time on the order of hours may be required for such an action.

In California, earliest concern over curtailability of QFs arose from an unexpectedly high response to supply programs. The combination of attractive long term guaranteed rates and no capacity limits had led to a "gold rush" of suppliers in the mid 1980's (Kahn, 1988, ch. 6). With California utilities experiencing a glut of capacity, the ability to refuse expensive QF purchases in off-peak hours became a valuable prerogative. We now discuss methods of quantifying the value of curtailability.

<u>Economics of curtailment</u>

Curtailability, as a bid characteristic, has the unique quality of not being entirely a non-price factor. In a way, curtailability is both a price and a non-price factor. Before we can describe how this is so, a brief overview of electric utility system economics is necessary.

Electricity is a non-storable product. As such, capacity must be enough to cover demand in those hours of highest need. An electric utility system therefore consists of a collection of generating resources whose usage over a year can vary greatly. Generally the system will consist of a collection of *base-load* units - nuclear and hydro power- with low energy (per kwh) costs, *mid-range* units - some coal and combined cycle gas, and *peaking* units - usually gas or oil fired combustion turbines.

With some notable exceptions, the optimal way for a utility to commit its units is simply in ascending order of energy costs. This ordering is usually called the *merit order*. As demand levels from hour to hour change, so does the mix and output levels of the units committed. Thus, the least expensive (in energy costs) units will run the most. The *marginal unit* is the last one in the merit order to be called upon in that particular hour (e.g. for that level of demand). System marginal cost in that hour is thus the energy cost of the marginal unit, or of the next unit in the merit order if the marginal unit is dispatched at full output.

Electricity demand over a time period such as a week or year is often represented in a *load duration curve* (LDC). An LDC is essentially a right cumulative demand distribution that displays load level (kilo-watts, kw) on one axis and on the other axis the number (or %) of hours in that given time period for which demand is at or above that kw level (Figure 1). From the LDC one can roughly determine the number of hours a particular unit can be called upon to operate by "stacking" the merit order under the LDC.

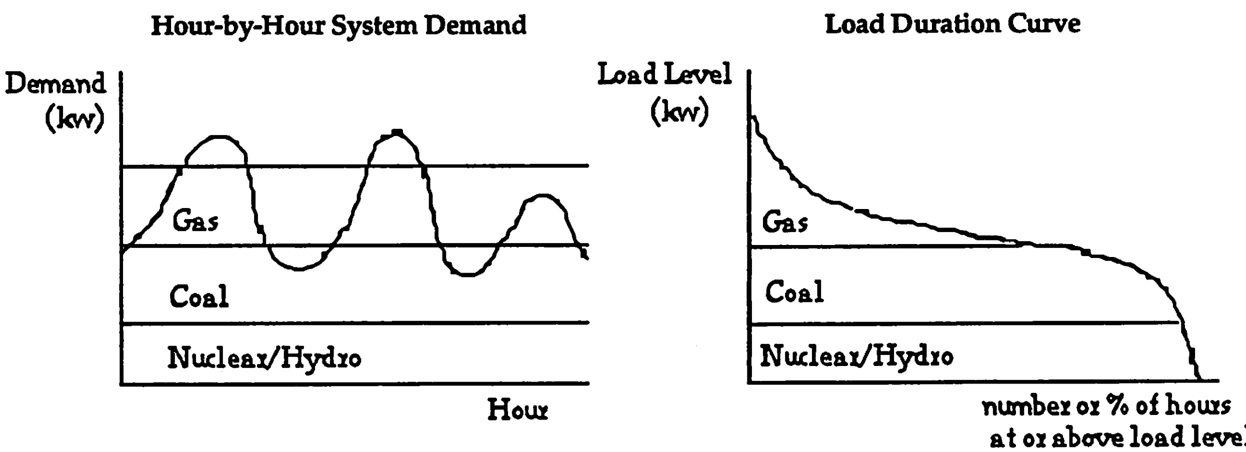

Figure 1: Load Duration Curve

This remarkably simple analysis is facilitated by the convenient property that optimal commitment in any hour is determined by moving up the merit order. The limitation of this analysis is that load duration curves treat all hours with the same load level as the same. Unfortunately, when inter-temporal constraints such as unit minimum down times and hydro depletion are considered, the ascending cost merit order may no longer be optimal. The degree of significance of these constraints is an active area of debate. It is generally considered - perhaps out of computational necessity - that for long range planning sophisticated versions of LDC analyses suffice.

Curtailability as a price factor

The obvious benefit to the utility of curtailability of a generating resource is the ability to not purchase power when it can generate it for less than the QF energy price. This is how curtailability can be viewed as a price factor. The cost in an hour during which the utility can't curtail is easily quantifiable - simply subtract system marginal cost from QF price. This concept can be extended to a full year using duration curves. Just as demand levels can be represented by a load duration curve, a cost duration curve displaying hours vs. level of cost can be constructed. From this curve, the per kw cost to the utility of a non-curtailable resource is the difference between the utility's system cost and the QF's energy price in those hours in which system cost is below that energy price (Figure 2). The benefit to the QF depends primarily upon the relation between payment price and the QF's true energy cost.

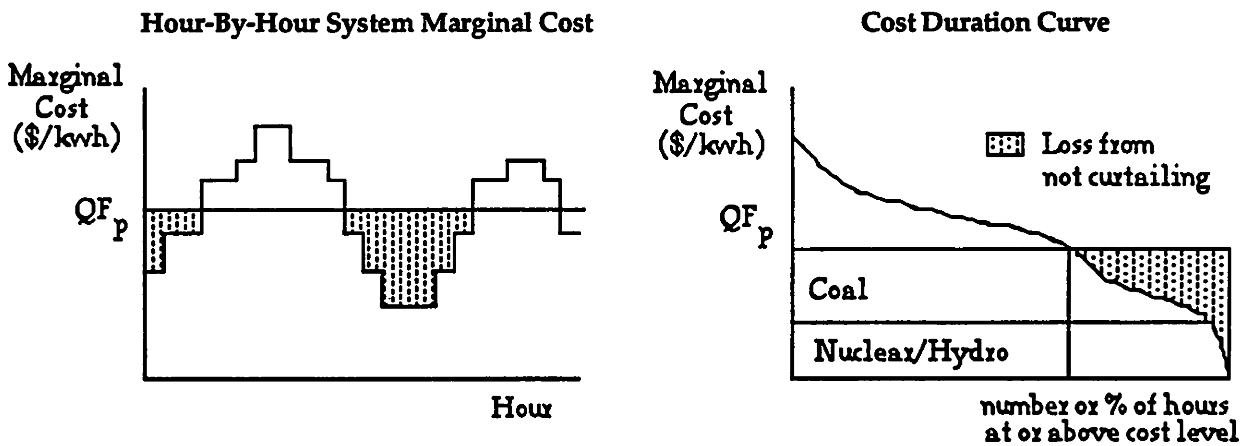

Figure 2: Electric System Marginal Cost

Curtailability as a non-price factor

The shortcomings of the LDC-based analysis which we briefly discussed earlier also cloud the issue of curtailability and produce effects that are truly non-price factors. Operational constraints such as minimum down times and ramp rates[2] make responding to rapid demand changes with base load units impractical. Such units are also much less efficient when operated at their

[2]A ramping rate refers to the amount of time needed to bring a generating unit's output up to full capacity.

minimum load levels than when at full output. Thus, it is sometimes the case that to optimize over the week's dispatch, a controller must shut down peaking units even when system marginal cost is above those units' operating cost in that hour. Full dispatchability gives central dispatchers the flexibility to optimize system operations and thus yields benefits that are difficult to quantify analytically. Kahn, Stoft, Berman, and Grahame (1991) study the use of electric utility simulation models for estimating the non-price benefits of curtailability.

When the capacity contribution of the QFs represents a small portion of overall utility system capacity, the non-price effects become negligible. Under those conditions, LDC-type analysis of the benefits of potential capacity additions is considered sufficient. In this paper we will focus on such situations and concentrate on prices and their relationship to curtailability.

Electric Power Auctions

Previous literature on electric power auctions has often focused on the prudency of using first or second price auctions. The California Public Utilities Commission (CPUC, 1990) has embraced the second price auction due to its' belief, based on the analysis by Vickrey (1961), that a second price auction will preclude strategic behavior by bidders. The CPUC hopes that "truth-telling" will be a dominant strategy for bidders, therefore eliminating the danger that asymmetric beliefs amongst bidders might lead to an inefficient allocation of supply contracts.

Rothkopf, Tsieberg, and Kahn (1990) show that in situations where bidders need to acquire inputs from third parties that possess some market power, those third parties may be able to extract any observed windfalls from the auction. The presence of such third parties provides strong incentive for *not* revealing true costs in the context of a second price auction. Simulation of an asymmetric bidding game has been used (Kahn, et. al. 1990) to study potential efficiency losses. It was shown that a bidder's choice of capacity size, and thus of production cost when economies of scale are present, mitigates the efficiency losses that might occur in single price, asymmetric auction. Einhorn (1988) argues that both first and second price sealed auctions have severe shortcomings. He proposes a series of two-part tariffs, negotiated between suppliers and the purchasing utility with the knowledge that a "fair" contract is an available option to all suppliers.

In all of the above literature, the power purchased by the utility is "must take." Therefore, the debate over the efficiency of different auction forms in these models considers only the efficient *acquisition* of low-cost capacity; the operational efficiency of the resulting system is not considered. Bolle (1991) shows that QF auctions can theoretically be efficient in this generalized sense, but he does not specifically address the issues that curtailability brings to evaluating bids. In fact, none of this work addresses specific industry practices. A recent study by Stoft and Kahn (1991) investigated the existence of scoring "bias" in auctions that did require curtailability. They show that the practice of "ratio" scoring - using percentage of avoided production cost as a basis for ordering bids - favors peak-load (high energy cost) generation.

3. Auctions with Fixed and Variable Price Bids

For an electric power auction requiring full curtailability of bidders to be both operationally and acquisitionally efficient, bidders must be ranked over two dimensions, fixed and energy costs. In this section we examine characteristics of bidding systems that incorporate both a fixed and a variable (energy) price into a net score. We specifically wish to examine what conditions are necessary for inducing bids in which energy prices are the same as costs. In other words, under which bid-scoring systems is it reasonable to expect bidders to state their actual operating costs as their energy price?

A further topic of interest concerns second price auctions. In an auction with both fixed and variable price components, it is not immediately obvious what the *second price* is. What form of payment, if any, leads to an equilibrium where actual costs are bid for both fixed and variable components?

These questions are in part motivated by bidding procedures under consideration by the California Public Utilities Commission (CPUC, 1990). The proposed scoring system will include (among other non-price factors) fixed and energy cost components. Curtailment based on energy price is expected from accepted suppliers. Successful bidders will be paid their bid energy price and a fixed price based on the *total price* of the lowest losing bid. The CPUC hopes this system will lead to bids that equal costs for both fixed and variable cost components.

We have discussed some literature concerned with the efficient acquisition of generation capacity. Electric power auctions may also lead to *operating* inefficiencies. For example, a QF may have higher costs than the utility's own resources, but may bid an energy price lower than both its own costs and those of the utility. The bidder could subsidize this operating loss by padding its fixed cost bid. The utility would then operate the QF before its own since that resource is "cheaper" from the utility's perspective. From a social efficiency perspective, however, such a merit order would be sub-optimal.

When the independent resources are not curtailable, the problem is exacerbated. In such instances the utility is no longer free to dispatch on the basis of energy payments, which themselves may not reflect costs.

First Price Auction

The analysis presented in this section is of a symmetric, private values auction. Bidders are assumed to be risk neutral and to know their own true costs at the time they submit their bids. Bidders do not know the costs of other bidders but estimate their opponents' costs to be independently drawn from a common joint probability distribution. Winners will receive in payment exactly the amount they have bid (first price auction). The level of curtailment is decided by the utility and is based upon bid energy price. The structure is similar to that of Hansen (1988) who studied auctions with endogenous quantities over one dimension, unit cost.

Auction Model Characteristics

The following parameters characterize bidder i in this model.

G_i	True fixed costs (\$/kw)
c_i	True variable costs (\$/kwh)
K_i	Bid fixed price (\$/kw)
p_i	Bid variable price (\$/kwh)

All bidders are assumed to draw their costs out of a common joint probability distribution $f(c,G)$. The generation capacity (size) of bids is not explicitly treated in this model. Instead, all bids are evaluated on the basis of score per unit of capacity. The purchasing utility combines the two price components in some way. For now, we assume a fixed bid of K adds -K towards the net score. A bid of p_i contributes $VS(p_i)$ to the net score - where $VS(p_i)$, the "variable score" of bid i, is defined by the bid-scoring system. The total score is thus $-K + VS(p_i)$.

Through some dispatch method, the utility estimates that a resource with energy price p_i will be dispatched (not curtailed) for $\rho(p_i)$ hours during a year. $\rho(p_i)$ can be considered a demand function that gives the quantity sold by a successful bid with variable price p_i. The function $\rho(p_i)$ is assumed known to all bidders as well as to the utility.

One goal of a bidding system is to induce truthful energy cost bidding, thereby permitting efficient electric system dispatch. We therefore examine possible strategies of bidders in which true energy costs are bid. For now, we allow strategies that are completely general in determining the fixed price bid, given that the energy price bid is equal to operating costs.

Assume that the common strategy of bidders is as follows:

1. Bidders bid $p_i = c_i$ (true variable cost)
2. Bidders bid a fixed price $K_i(G_i,c_i)$ that is a function of both fixed and variable costs. $K(G,c)$ is assumed to be differentiable in both G and c

This strategy essentially places all strategic behavior into the fixed portion of the bid. Such strategies send accurate variable cost signals to the purchasing utility and therefore results in socially efficient operations.

It is interesting to examine the contour sets of a two-dimensional bidding function such as $K(G,c)$. Assuming that the fixed price bid $K(G,c)$ is monotonically increasing in G, decreasing in c, and continuous, isoquants for a common fixed bid $K(\cdot\cdot) = x$ would look something like the line labeled "$K(G,c) = x$," pictured below (Figure 3).

However, due to the inclusion of variable price considerations in the total bid score, the combinations of fixed and variable costs that would result in the same *total score* are represented by the line labeled "iso-score" below. Since low variable costs are considered a positive benefit by the bid taker, bids on the southeast portion of the K(G,c) isoquant would have better overall scores.[3]

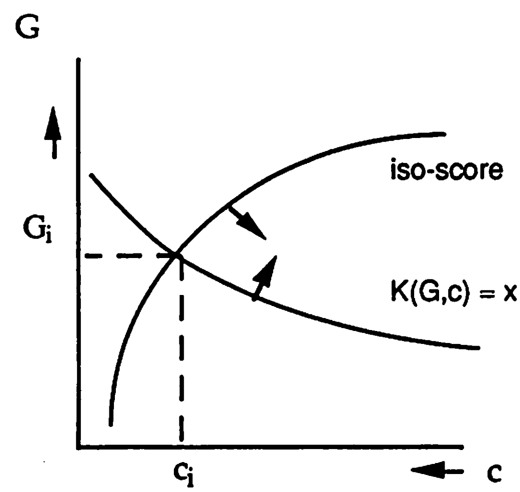

Figure 3: Fixed Price Bid and Total Score Isoquants

[3] The iso-score curve, as drawn in Figure 3, shows an implicit assumption that total score is decreasing in both energy and fixed cost when the strategy outlined above is employed. This point makes sense intuitively, but the effect of energy cost on score is in fact indeterminate at this point of the analysis.

Necessary Conditions

We now present necessary conditions of the scoring procedure for such a bidding strategy to be an equilibrium. Assume that all bidders follow the strategy outlined above. The energy price is set at true energy cost and the fixed price is a general function of fixed and variable costs.

Bidders must then choose what costs to "reveal" through the bidding process. Note that reveal is a relative term. That a bidder reveals his or her true costs through the function K(G,c) indicates only that the strategy outlined above is an equilibrium one. The fixed prices seen by the bid taker will not be the true fixed cost, although theoretically true costs can be calculated through the function K(G,c). The bidder's revelation problem will be to maximize profit π, and can be expressed as

$$\text{Max}_{G,c}\ E(\pi_i(G,c)) = (K(G,c) - G_i + (c-c_i)\rho(c))\Pr(\text{i's bid wins}).$$

The probability that i's bid wins (given everyone follows a strategy of the form described above) will be the probability that i's score is the highest. To describe this probability we need to introduce some further notation.

$$\text{Define } K_c^{-1}(x) \text{ as } \{G \mid K(G,c) = x\}$$

$K_c^{-1}(x)$ is the fixed cost G for which, when combined with energy cost c, the function K(G,c) results in a fixed price bid of x.

In the two-player case i's probability of winning can be written as

$$\begin{aligned}\Pr(\text{i's bid wins}) &= \Pr(-K(G_i,c_i) + VS(c_i)) \text{ is highest})\\ &= \Pr(-K(G_i,c_i) + VS(c_i) > -K(G_j,c_j) + VS(c_j))\\ &= \Pr(K(G_j,c_j) > K(G_i,c_i) - VS(c_i) + VS(c_j))\end{aligned}$$

$$\Rightarrow \quad \Pr(\text{i's bid wins}) = \int_0^{\infty}\int_{(\theta(c_j,G_i,c_i))}^{\infty} f(c_j,G_j)\,dG_j\,dc_j$$

Where $\theta(c_j,G_i,c_i) = K_{c_j}^{-1}[K(G_i,c_i) - VS(c_i) + VS(c_j)]$. $\theta(c_j,G_i,c_i)$ represents the value of G_j that results in a tie between the scores of i and j given that the other bid characteristics are c_j, G_i, and c_i. The formulation is easily extended to cases with multiple bidders and n winners by interpreting $f(\cdot\cdot)$ as a density of the nth order statistic distribution.

Proposition 1: *A necessary condition for a strategy involving truth-telling of energy costs to be a Bayesian-Nash equilibrium is*

$$(1) \qquad \rho(c_i) = -\frac{dVS(c_i)}{dc_i}$$

A proof is provided in the appendix. Condition (1) states that the bidders' marginal rates of substitution between fixed and variable components in the scoring has to be the same as the rates of substitution reflected in the payments made to winners at the point of truth-telling of energy costs. This condition gives insight into *price* scoring methods that should be adopted by utilities and regulators. Auction designers should also be alert for *non-price* factors that distort the relative value of fixed and energy payments to the bidders. Such distortions can destroy the possibility of equilibria in which energy costs are truthfully bid.

Second Price Auction

Consider an auction identical to the one described above except that the fixed portion of the payment is to be based upon the best *losing* bid (second price auction). Our goal is to find the form of fixed payment that results in truthful bids of both fixed and energy costs.

Using the intuition developed in the analysis of the first price auction, we directly examine a bidding strategy consisting of simply telling the truth. The probability of bid i succeeding in a two-player game if both bidders follow this strategy is therefore the probability that the other bid has a lower total score. Total score in this case is computed using true costs.

$$\begin{aligned}\Pr(\text{i's bid wins}) &= \Pr(-G_i + VS(c_i)) \text{ is highest}) \\ &= \Pr(-G_i + VS(c_i) > -G_j + VS(c_j))\end{aligned}$$

$$\Rightarrow \qquad \Pr(\text{i's bid wins}) = \int_0^\infty \int_{VS(c_j)+G_i-VS(c_i)}^\infty f(c_j,G_j)dG_j dc_j$$

With complete truth telling by bidders, the two-dimensional aspect of the bids is reduced to one dimension by the scoring function. Iso-score level sets can thus be drawn in (G,c)-space. The probability of an individual bidder succeeding therefore is the probability that all other bids lie in the individual's lower contour set in (G,c)-space (see Figure 4).

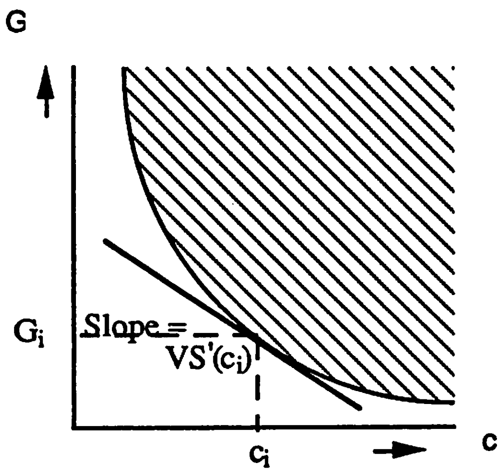

Figure 4: Region of Bidders Who Will Lose to Bidder i

We now present conditions for which truthful bidding can be a Bayes-Nash equilibrium. We examine the first-order conditions of the bidder's maximization problem taken at true costs and assuming that all other bidders are bidding their true costs. Let K_{sp} represent the payment made to winners based on the lowest losing bid (second price).

<u>Proposition 2</u>: *Assume that bidder i has the best bid and bidder j the second best. Setting $K_{sp} = G_j + VS(c_i) - VS(c_j)$, along with condition (1), meets first-order conditions for truth telling to be a Bayes-Nash equilibrium of this model.*

Proof of this proposition also is provided in the appendix. The value of K_{sp} given in proposition 2 makes a fixed payment to the winning bidder equal to the winning bidder's fixed bid plus *the difference in total score* between the first and second best score. A payment of this type agrees with the analysis of Bolle (1991), who argues qualitatively for permitting the first best bidder to receive a fixed payment such that the net surplus of the utility is the same as if the second best bid had been selected.

4. Scoring Procedures

To give more insight into the conditions presented above, we now present a sample scoring procedure that meets those conditions and also has intuitive physical meaning. We then examine two existing scoring systems, that of the Consolidated Edison Co. and one proposed to be employed in future auctions in California. All three scoring systems employ cost-duration curves for estimating the hours of dispatch proposed resources will receive.

As described earlier, a cost-duration curve displays the number of hours during a time period (such as a year) for which system marginal costs are expected to be above a certain cost level. An additional capacity unit (kw) with energy cost c can be expected to displace one kw for ρ(c) hours during that period. The avoided cost of the utility can therefore be estimated as the area under the cost duration curve and above the cost level c.

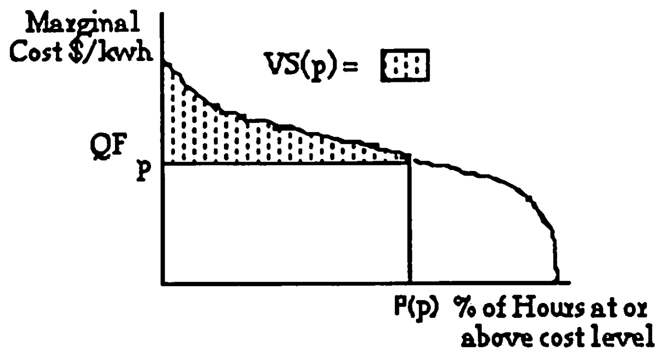

Figure 5: Cost duration curve estimate of avoided cost

Our scoring system calculates benefits in this way. For our purposes, it is sometimes easier to consider the inverse of the cost duration function ρ(c), which we will call s(ρ).

The scoring procedure is as follows:

1. A fixed price K gives a negative score of -K.
2. An energy price c gives a variable score of $\int_0^{\rho(c)}[s(\rho) - c]d\rho$.

Where ρ(c) is the number of hours a unit with energy cost c is expected to operate. This scoring method thus determines the net savings to the utility over the ρ(c) hours in which the new unit will operate. It is analogous to estimating consumer surplus by calculating the area under a demand curve.

Note that no explicit value has been given for the avoided *capacity* costs that the independent resource provides. We adopt the convention used by the CPUC that all bidders receive the same avoided capacity credit (provided they meet reliability standards that are not discussed here). Thus successful bidders know they will receive a pre-specified capacity payment in addition to the values determined by the bidding procedures.

We now verify that this scoring method satisfies condition (1). For the bid scoring system given above, we have that:

$$\frac{dVS(c_i)}{dc_i} = [s(\rho(c_i)) - c_i]\rho'(c_i) - \int_0^{\rho(c_i)} d\rho$$

but $s(\rho(c_i))$ is simply c_i, leaving

$$\frac{dVS(c_i)}{dc_i} = -\rho(c_i)$$

The use of a cost duration curve implicitly takes into account questions of optimal capacity "mix" through the shape of the curve itself. It is, however, limited by the extent to which cost duration curves may be accurately estimated. This approach also ignores the hour-to-hour interaction of system generation units, which is lost through the aggregation of all hours into one curve. Once again, if the capacity that is added is small relative to the utility's overall system capacity, these effects are not believed to be significant.

We now examine two existing bid scoring procedures. We must stress that the analysis below discusses only the scoring of fixed and variable prices. We present a simplified version of these systems to focus on how the two prices are combined into a net score and, in the case of California, on the "second price" payment that is paid to successful bidders. There are many additional non-price factors that affect the total net score of a bid. These other aspects of the scoring system, such as environmental benefits and availability-based capacity payments, make the actual scoring considerably more complicated than in the models presented above.

Consolidated Edison System

Consolidated Edison (CE 1988) allowed bidders to state a "range" of allowable curtailment hours and adjusted price scoring accordingly. In this analysis, we assume that the number of curtailment hours preferred by the purchasing utility will fall within the range offered by the bidder. The CE system computed a projected cost for providing a kw-year of power from the combined sources of the bid project and the utility system. The cost of power from the bid project was simply bid fixed price plus bid variable price times the projected optimal number of dispatch hours. To this annual price was added the cost of providing power in "make-up hours" (i.e. those hours during which the bid project would be curtailed). The cost of make-up hours is represented by the shaded area on the right of Figure 6. Total variable score is the sum of the two shaded areas below. It is important to note that the *low score* wins in this format, unlike the analysis above.

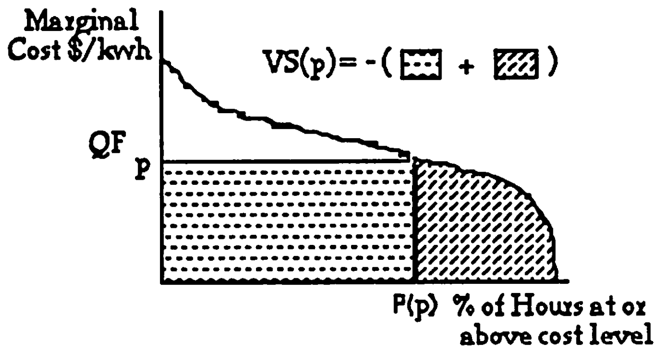

Figure 6: CE Variable Scoring Method

Using the scoring conventions of section 3, the total score of a bid is thus

$$-K - p\rho(p) - \int_{\rho(p)}^{1} s(\rho)d\rho,$$

where s(ρ) is the inverse of ρ(p). We now verify that this scoring method satisfies the condition of proposition 1. For the bid scoring system given above, we have that:

$$\frac{dVS(p)}{dp} = -\rho(p) - p\rho'(p) - s(\rho(p))\rho'(p)$$

but s(ρ(p)) is simply p, leaving

$$\frac{dVS(p)}{dp} = -\rho(p)$$

The CE system is equivalent to our sample procedure presented above. A marginal changte in energy bid will have the same marginal effect on score in both systems. One can see this graphically - increasing the shaded area in figure five is forces an equivalent reduction in the shaded areas of figure 6.

California Utilities System

The proposed California system (PG&E 1992) scores bids in ($/kwh) units, rather than the ($/kw) units used in the analysis above. Let K_i be bidder i's fixed price bid and p_i be his energy price bid. Bidder i's net score becomes:

$$\text{Total score} = p_i + \frac{K_i}{\rho(p_i)}$$

where $\rho(p_i)$ represents the estimated number of hours in which the resource will *not* be curtailed.[4] Note that in this auction also the *low* bid wins. Since the units used to score bids are not the same, we cannot directly test for the condition in proposition 1. We can however, construct an analysis similar to the one presented above. All the assumptions used in the previous sections also apply here.

California plans to institute a second price auction in which the fixed payment will be $K_{sp} = [K_j/\rho(p_j) + p_j - p]\rho(p)$, where bidder j is the lowest losing bidder. The expected profits upon winning the auction are unchanged from above, however, the probability of winning must be re-evaluated. Using the California scoring procedure, the probability that bidder i will be successful in the two-bidder case, provided that both bidders follow a truth-telling strategy, can be written as:

$$\begin{aligned}
\Pr(\text{i's bid wins}) &= \Pr\{K(G_i,c_i)/\rho(c_i) + c_i \text{ is lowest}\} \\
&= \Pr\{K(G_i,c_i)/\rho(c_i) + c_i < K(G_j,c_j)/\rho(c_j) + c_j\} \\
&= \Pr\{K(G_j,c_j) > [K(G_i,c_i)/\rho(c_i) + c_i - c_j]\rho(c_j)\} \\
\Rightarrow \quad \Pr(\text{i's bid wins}) &= \int_0^\infty \int_{(\psi(c_j,G,c))}^\infty f(c_j,G_j)\,dG_j\,dc_j
\end{aligned}$$

where $\psi(c_j,G,c) = K_{c_j}^{-1}\{[K(G,c)/\rho(c) + c - c_j]\rho(c_j)\}$.

The second price payment is set more or less in agreement with the analysis of second price auctions given above. However, the bidders' marginal rates of substitution between fixed and variable prices are not correctly reflected in the scoring. This causes the truth-telling properties of the second price auction to break down.

---

[4] In actuality, independent resources, upon being asked to curtail, are only required to curtail to 30% of their capacity. Energy above 30% of capacity during curtailment hours could be sold, but at the utility's avoided cost, rather than the resource's bid price. These options may cause further difficulties for energy cost revelation, but do not affect the incentive problem shown below, so for ease of exposition we have left them out of our representation of the scoring system.

Proposition 3: *Using the proposed California scoring system, there cannot exist an equilibrium in which variable costs are truthfully bid.*

A proof is provided in the appendix. Obviously there are many other factors that affect a bidder's decision. We readily admit that our representation of the California scoring system is a simplified one that ignores factors unrelated to curtailability. However, the decision to adopt a second price auction in California was based in large part upon models even simpler than the ones presented here. We therefore argue that these results call into doubt the expectation that the newly adopted scoring system will result in truthful cost bidding by participants.

5. Second Price Auction Example

We now present a simple example to illustrate bidder strategies in a *second price* auction like the ones described above. A two-bidder game is presented. Both cost parameters are assumed to be in the range $G,c \in [0,1]$. Assume that the probability density of values over this unit rectangle is uniform. The shape of the cost-duration curve is assumed to be triangular with range and domain [0,1]. The dispatch function $\rho(p)$, interpreted here as the percentage of hours at or above c, is therefore defined as 1 - p.

Consolidated Edison System

Variable score is the area below p and below the cost-duration curve (figure 7). Thus, we have $VS(p) = -p(1-p) - \frac{1}{2}p^2$.

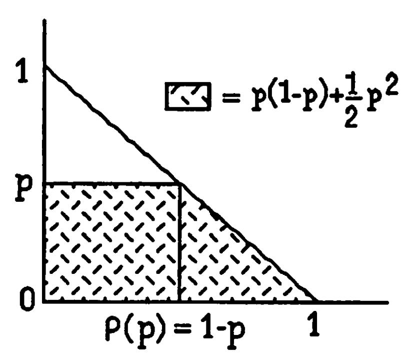

Figure 7: Consolidated Edison Variable Score

Parameters for 2nd price auction example

G,c	$\in [0,1]$
$f(c,G)$	dGdc
$\rho(p)$	1 - p
K_{sp}	$-G_j+VS(c_j)-VS(p)$
VS(p)	$-(p\rho(p)+\frac{1}{2}p^2)$

Under a second price auction with payment set at K_{sp} described above, the expected profit, π, of bidder i as a function of his bid, (K,p), given that j follows the truth telling strategy, is:

$$\text{Max}_{K,p}\, E(\pi_i(K,p)) =$$
$$\int_0^1 \int_{\text{Max}(0,K-VS(p)+VS(c_j))}^1 [G_j - [p(1-p)+\tfrac{1}{2}p^2] + [c_j(1-c_j)+\tfrac{1}{2}c_j^2] - G_i + (p-c_i)(1-p)]dG_j dc_j$$

This function is plotted in Figure 8 below for values of $G_i = c_i = .25$. We know from the preceding analysis that first order conditions are met where K and p both equal .25. Figure 8 shows that this point (truth-telling) is indeed the optimum over the feasible range. For this example, truth-telling is a Bayes-Nash equilibrium.

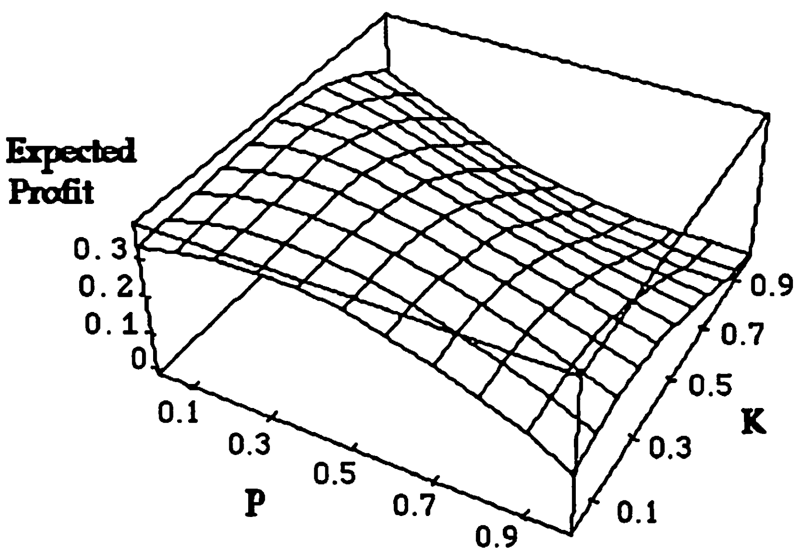

Figure 8: Expected Profit of Bidder i
$G_i = .25$, $c_i = .25$

CPUC system

Once again, the California scoring procedure is as follows.

$$\text{Total score} = p_i + \frac{K_i}{\rho(p_i)} = p_i + \frac{K_i}{1-p_i} \quad \text{for this example.}$$

To avoid a variable score of zero (and thus a total score of ∞), we limit the feasible range of cost to [0,.5]; once again, both costs are assumed to be uniformly distributed in this range.

$$f(G,c) = \begin{cases} 4 & 0 \le c \le .5 \\ & 0 \le G \le .5 \\ 0 & \text{otherwise} \end{cases}$$

For bidder i, expecting his opponent to bid truthfully, expected profits as a function of his own bid, (K,p), are:

$$\mathrm{Max}_{K,p}\, E(\pi_i(K,p)) =$$

$$\int_0^{.5}\int_{0\le(K/(1-p)+p-c_j)(1-c_j)\le .5}^{.5}\{[G_j/(1-c_j)+c_j-p](1-p)-G_i+(p-c_i)(1-p)\}f(c_j,G_j)\,dG_j\,dc_j$$

The values of this function for $G_i = c_i = .25$ are plotted below in Figure 9. We have indicated that truth-telling cannot be an equilibrium in this model. Figure 9 shows that it is optimal for bidder i to deviate to a strategy of bidding zero variable cost and full fixed cost.

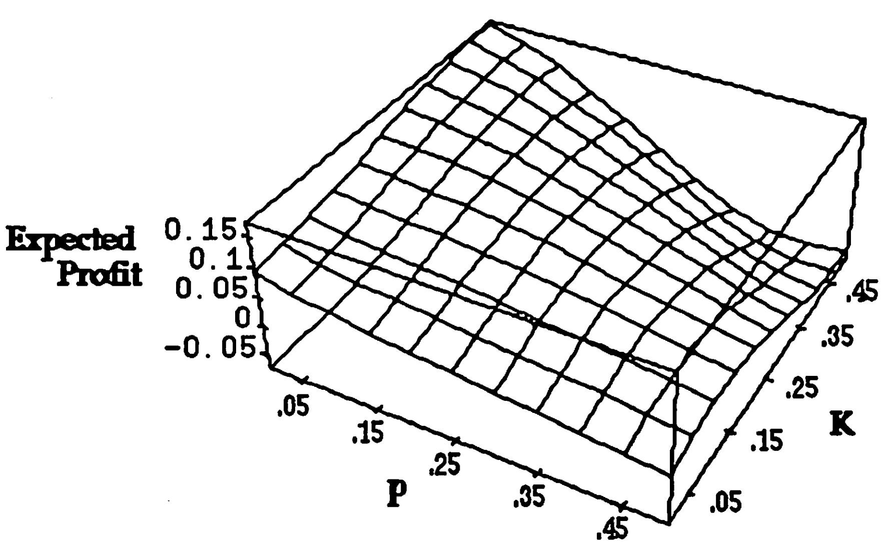

Figure 9: Expected Profit of Bidder i, California System
$G_i = .25$, $c_i = .25$

6. Conclusions

The restructuring of the electric power industry into one in which generation is competitively supplied will most likely lead to informational problems that did not exist when the industry was fully vertically integrated. As we have argued, some of these informational problems may arise from strategic behavior of bidders competing in auctions to sell power to utilities. The fact that informational constraints can produce negative reliability and efficiency effects should be recognized by policy makers.

At the same time, informational problems can be mitigated by carefully considered auction design. We have shown that a potential information problem is the transfer of inaccurate cost signals from suppliers to a centrally controlled dispatch process. Bid scoring systems must meet the condition that the marginal rates of substitution between price components be the same in the payments made to winners as in the method of scoring bids if truthful bidding of energy costs is to be feasible.

This condition provides useful insight into scoring provisions involving non-price factors as well. Any scoring provision that alters the relative values placed on fixed and variable payments to suppliers has the potential to destroy equilibria in which energy costs are accurately revealed. A prime example of this issue is the proposal to pay environmental bonuses to clean suppliers that are based upon hours of operation - and thus indirectly upon bid energy price. Future work should examine the effects of such composite scoring on bidder strategies.

One assumption that is implicit in this model is the single time period nature of the payments. In fact, contracts resulting from electric power auctions are multi-year agreements. The practice of escalating payments due to discount rates or fuel price indices will most likely affect the relative values of fixed and energy payments to both suppliers and the purchasing utility. A multi-period model therefore also seems to be a useful extension.

Appendix

Proof of proposition 1:

Assume all bidders adopt the strategy of bidding an energy price equal to energy cost and bidding a fixed price according to the function K(G,c). If the strategy is an equilibrium one, the expected profit of each bidder as a function of the costs revealed through the strategy function must be maximized at the truth-revealing point. Having adopted the strategy above, bidder i will choose G and c to maximize his expected profit:

$$E(\pi_i(G,c)) = [K(G,c) - G_i + (c-c_i)\rho(c)]\int_0^{\infty}\int_{(\theta(c_j,G,c))}^{\infty} f(c_j,G_j)dG_jdc_j.$$

The first order conditions taken at G_i, c_i are as follows

$$(1)\quad \frac{dE(\pi_i(G_i,c_i))}{dG} = \frac{\partial K}{\partial G}\int_0^{\infty}\int_{(\theta(c_j,G,c))}^{\infty} f(c_j,G_j)dG_jdc_j - [K(G,c) - G_i]\left\{\int_0^{\infty} f(c_j,\theta(c_j,G,c))\frac{dK_{c_j}^{-1}(\eta)}{d\eta}dc_j\right\}\left\{\frac{\partial K}{\partial G}\right\} = 0.$$

$$(2)\quad \frac{dE(\pi_i(G_i,c_i))}{dc} = \left[\frac{\partial K}{\partial c} + \rho(c_i)\right]\int_0^{\infty}\int_{(\theta(c_j,G,c))}^{\infty} f(c_j,G_j)dG_jdc_j - [K(G,c)-G_i]\left\{\int_0^{\infty} f(c_j,\theta(c_j,G,c))\frac{dK_{c_j}^{-1}(\eta)}{d\eta}dc_j\right\}\left\{\frac{\partial K}{\partial c} - \frac{dVS(c_i)}{dc_i}\right\} = 0$$

Where $\eta = [K(G_i,c_i) - VS(c_i) + VS(c_j)]$ and $\theta(c_j,G_i,c_i) = K_{c_j}^{-1}[\eta]$.

If the first condition holds we have:

$$\int_0^{\infty}\int_{(\theta(c_j,G,c))}^{\infty} f(c_j,G_j)dG_jdc_j = [K(G,c) - G_i]\left\{\int_0^{\infty} f(c_j,\theta(c_j,G,c))\frac{dK_{c_j}^{-1}(\eta)}{d\eta}dc_j\right\}$$

but if this is true, the second condition can only hold if:

$$\rho(c_i) = -\frac{dVS(c_i)}{dc_i},$$

which concludes the proof.

Proof of proposition 2:

Bidder i's maximization problem in the second price auction with payment K_{sp}, given that the others are using a truth-telling strategy, is:

$$\text{Max}_{G,c}\, E(\pi_i(G,c)) = \int_0^\infty \int_{VS(c_j)+G-VS(c)}^\infty [G_j+VS(c)-VS(c_j)-G_i+(c-c_i)\rho(c)]f(c_j,G_j)dG_j dc_j$$

The first order condition for the fixed price (taken at G_i,c_i) is:

$$(4)\quad \frac{dE(\pi_i(G_i,c_i))}{dG} =$$

$$-\int_0^\infty [VS(c_j) + G - VS(c_i) - VS(c_j) + VS(c_i) - G_i]f(c_j,VS(c_j)+G-VS(c_i))dc_j$$

$$= \quad -\int_0^\infty [G - G_i]f(c_j,VS(c_j)+G-VS(c_i))dc_j$$

$= \quad$ 0 only when $G = G_i$ (assuming $f(\cdot,\cdot)$ is not zero).

The first order condition for the energy price is

$$(5)\quad \frac{dE(\pi_i(G_i,c_i))}{dc} =$$

$$\int_0^\infty [VS(c_j)+G_i-VS(c)-VS(c_j)+VS(c)-G_i]\frac{dVS(c_i)}{dc}f(c_j,VS(c_j)+G-VS(c))dc_j$$

$$+\int_0^\infty \int_{VS(c_j)+G-VS(c)}^\infty [\frac{dVS(c_i)}{dc} + \rho(c) + \rho'(c)(c-c_i)]f(c,G)dG_j dc_j$$

$$= \quad \int_0^\infty [-VS(c) + VS(c_i)]\frac{dVS(c_i)}{dc}f(c_j,VS(c_j)+G-VS(c))dc_j$$

$$+\int_0^\infty \int_{VS(c_j)+G-VS(c)}^\infty [\frac{dVS(c_i)}{dc} + \rho(c) + \rho'(c)(c-c_i)]f(c,G)dG_j dc_j$$

$= \quad$ 0 at $c = c_i$ once again if $\rho(c) = -\dfrac{dVS(c_i)}{dc}$.

For auctions with variable scoring satisfies the condition in proposition 1 and that has fixed payment equal to K_{sp} above, truth telling meets (first-order) necessary conditions for a Bayes-Nash equilibrium.

Proof of Proposition 3:

In a two-player game where the bidders' strategies are to bid true costs, the probability of player i succeeding can be written as

$$\Pr(\text{player i wins}) = \int_0^\infty \int_{(G/\rho(c)+c-c_j)\rho(c_j)}^\infty f(c_j,G_j)dG_j dc_j.$$

The expected profit of bidder i is therefore

$$E(\pi_i(G,c)) = \int_0^\infty \int_{(G/\rho(c)+c-c_j)\rho(c_j)}^\infty \{[G_j/\rho(c_j) + c_j - c]\rho(c) - G_i + (c-c_i)\rho(c)\} f(c_j,G_j)dG_j dc_j.$$

It can be shown that the first order conditions for the fixed portion G, are met when $G = G_i$. However, the first order condition for the energy portion c, taken at $c = c_i$, is

(8) $$\frac{dE(\pi_i(G_i,c_i))}{dc} =$$

$$\int_0^\infty \{[G/\rho(c)]\rho(c) - G_i + \rho(c)(c-c_i)\}\{\frac{\rho'(c_j)G_i}{\rho(c_j)^2} + 1\}\rho(c_j) f(c_j,[G/\rho(c)+ c- c_j]\rho(c_j))dc_j$$

$$+ \int_0^\infty \int_{(G/\rho(c)+c-c_j)\rho(c_j)}^\infty \{[G_j/\rho(c_j) + c_j -c]\rho'(c) + \rho'(c)(c-c_i)\} f(c,G)dG_j dc_j.$$

After cancellation, when c and G are set equal to c_i and G_i, respectively, we are left with

$$\frac{dE(\pi_i)}{dc} = \int_0^\infty \int_{(G/\rho(c)+c_j-c)\rho(c_j)}^\infty \{[G_j/\rho(c_j) + c_j - c_i]\rho'(c_i)\} f(c,G)dG_j dc_j$$

In the likely event that the *total* score of bidder j is greater than the energy price of bidder i and $\rho'(c_i)$ is negative (non-zero), expected profits are decrease with respect to the energy bid c at the truth-telling value of $c = c_i$. Therefore, the California second price auction cannot induce an equilibrium of this model in which true costs are revealed.

References

Bolle, F. (1991), "On the Economics of PURPA Auctions," Energy Economics, Vol. 13, N2, pp.74-80.

California Public Utilities Commission. June, 1991. Decision No. 91-06-022.

Consolidated Edison Company (C.E. 1988), "Proposed Integrated Supply-Side and Demand-Side Bidding Program," December 1, 1988.

Einhorn, Michael A. (1990) "Purchasing Power for the Grid: A Social Contract Approach," *Resources and Energy*, Vol. 12, pp. 33-48.

Hansen, Robert J. (1988), "Auctions with Endogenous Quantities," *RAND Journal of Economics*, Vol. 19, No. 1, pp. 44-58.

Hulett, Stanley W. (1989), "Promoting Independent Power: The California Experience," *Public Utilities Fortnightly*, February 16, pp. 13-17.

Kahn, Edward. (1988), *Electric Utility Planning and Regulation*, American Council for an Energy Efficient Economy.

Kahn, E., S. Stoft, D. Berman, and T. Grahme (1991), "Optimization Methods for Evaluating Competitive Bids from Private Producers." *IEEE Transactions on Power Systems* 6(2), pp. 729-735.

Pacific Gas And Electric Company (1992), Settlement Agreement Regarding Changes to Final Standard Offer 4 and to Bid Evaluation Methodology. CPUC, Investigation 89-07-004.

Rothkopf, M., Tsieberg, T.J., and E. Kahn (1990), "Why are Vickrey Auctions Rare?," *Journal of Political Economy*, Vol. 98, no. 11, pp. 94 - 109.

Rothkopf, M., Kahn, E., Eto, J., and J.M. Nataf (1990), "Auctions for PURPA purchases: a simulation study," *Journal of Regulatory Economics*, Vol. 2, pp. 129-149.

Stoft, S., and E. Kahn, "Auction Markets for Dispatchable Power: How to score the Bids," *Journal of Regulatory Economics*, Vol. 3, pp. 275-286.

Summerton, Jane and Ted K. Bradshaw (1991), "Towards a dispersed electrical system: Challenges to the grid," *Energy Policy*, January/February, 1991, pp. 24-34.

Vickrey, William (1961), "Counterspeculation, Auctions and Competitive Sealed Tenders," *Journal of Finance*, 16:8-37.