7 ACTIVITY RULES FOR AN ITERATED DOUBLE AUCTION

Robert Wilson[*]

This chapter reports an application of game theory to market design. Like most practical work, it uses a few key principles derived from theoretical studies, rather than any particular model or explicit mathematical analysis.

The purpose of market design is to increase the efficiency of the market outcome by suppressing strategic behavior or rendering it ineffective. One part of this task is to eliminate loopholes in the procedural rules that might be exploited by a wily trader, but the more fundamental part is to devise rules that promote efficiency. In the case of an iterated multi-market auction, the key requirement is reliable price discovery. That is, the rules should encourage suppliers to reveal their costs, and demanders their values, steadily throughout the bidding process. This is necessary because any one supplier typically relies on the pattern of prices across the markets to devise its optimal bidding strategy, taking account of its variable and fixed costs of operation. Similarly, each demander relies on the pattern of prices to construct its optimal plan of purchases, taking account of complementarities and substitution among the products offered in the several markets. Efficiency of the final outcome therefore depends on early, and as the auction proceeds, progressively more accurate revelation by all traders.

The present application is to the design of a wholesale market for forward trades of electrical power among suppliers (generators) and demanders (large customers and power marketers). Such a market is typically conducted a day ahead of delivery, and consists of 24 separate markets for delivery during the 24 hours of the next day. Each of the hourly markets clears independently of the others, and all trades are settled at the clearing prices established at the close of the final iteration. This application was developed within the particular institutional features of the California Power Exchange (PX), which started operations on April 1, 1998 (see the website www.calpx.com for reports of transactions and prices). The PX is a public-benefit corporation that competes with other wholesale markets conducted by private parties.

Each of the PX's day-ahead hourly markets is a double auction. Each supplier submits an offered supply schedule indicating the quantity it is willing to provide at each price. Similarly, each demander's bid is a demand schedule indicating the quantity it wants to purchase at each price. The supply schedules are aggregated by computing the total supply offered at each price; similarly, the demand schedules are aggregated by summing to find the total demand at each price. The market is then "cleared" by finding the (least) price at which aggregate supply equals aggregate demand. In the static version of the double auction this closes the market: each supplier and demander is assigned the quantity it offered or bid at that price, and all transactions are made at the clearing price. The design task, however, called for an iterated double auction. In this dynamic version the entire process is repeated several times, allowing suppliers and demanders to alter their submissions in response to the prices and quantities resulting from previous iterations. The market closes only when no submissions are revised, or when a convergence criterion has been met.

The motive for an iterated auction is the important role of price discovery. As described in Section 1, a supplier needs to anticipate the pattern of clearing prices across the entire 24 hourly markets in order to make well-informed decisions about which generating units to start. In particular, the duration of a unit's consecutive hours of operation is a major determinant of whether the costs of start-up can be recovered. The efficiency of the market outcome is partly dependent on a reliable and informative process of price discovery as the iterations proceed.

The basic design problem can be stated simply. The "gaming" behavior that could undermine price discovery, and thereby efficiency, is the strategy called "hiding in the grass." This refers to the tactic of deferring serious bidding until the close of the auction. If the rules allow such a strategy then each trader prefers to wait until the final iteration, when it can see the pattern of hourly prices revealed by others' bids, and then devise its own optimal bids accordingly; moreover, by waiting it avoids affecting interim prices via its own bids. But if many traders do this then price discovery is impaired, and the efficiency gains from an iterative process are lost, since only the final iteration reflects sufficient serious bids to establish the pattern of prices. Thus, the underlying difficulty is a free-rider problem in which each trader prefers that others provide the bids that reveal the pattern of hourly prices.

One solution, albeit a partial one, is to impose "activity rules" of the kind used in the FCC spectrum auctions. The role of such rules is to encourage serious bidding right from the start. The key idea is to confront traders with irreversible decisions throughout the iterative process. At each stage a trader faces a "use it or lose it" decision regarding the bidding options available in later iterations. Activity rules must be designed carefully to minimize adverse effects on efficiency from restricting traders' bidding strategies, but if designed well then they benefit each trader by encouraging others to bid seriously in each iteration. The resulting progressive revelation of the pattern of prices across the markets enables each trader to take advantage of this information in constructing its own bids.

The activity rules described here are based on the principle of revealed preference: a bidder's refusal to improve a previous clearing price is presumptive evidence that it cannot do so profitably. This principle is represented by an "Exclusion Rule" that prevents later improvements in an offer that fails to improve the previous clearing price at the first opportunity. When other routine procedural rules are included, the resulting activity rules perform well in experimental tests, as described by Plott (1997).

The motivation for the activity rules is described in Section 1. The specific rules proposed for the PX are described in Section 2 and elaborated in Section 3. The full set of activity rules is summarized in the Appendix.

1. The Role of Activity Rules

Self-scheduling is a principal feature of the PX auction. Bids and offers are for delivered energy only – transmission losses are absorbed by demanders; all traders incur usage charges for transmission across congested inter-zonal lines; and fixed cost components such as start-up and no-load hourly running costs are absorbed by suppliers, who offer energy from their portfolios of generation assets. The iterative character of the PX is motivated primarily by suppliers' need to recover the fixed costs of daily operations: as the pattern of hourly prices is revealed during the iterations, suppliers are better able to schedule the plants in their portfolios to meet the energy commitments in their accepted offers.

There are several other market designs that provide some assurance that fixed costs are covered. One type allows offers on a full-cost basis; this type includes bilateral bid-ask markets and auctions that allow combination tenders for multiple hours. A second type is represented by the PX auction protocol, in which an iterative auction process enables a supplier to select its operating regime, withdrawing from hours with prices insufficient to cover its total costs. If price discovery is early and reliable then self-scheduling is feasible and there is no need for the system operator to optimize operating schedules.

The role of withdrawals in the PX is due to an interaction between the tender format and the pricing rule. The tender format requires separate offers for each hour. The uniform-price rule stems from the legislated requirements that in each hourly market all energy is traded at the market clearing price, exclusive of transmission usage charges, and that the PX takes no net position. Uniform pricing can be implemented without withdrawals, as in the uniform-price double auction studied by McCabe, Rassenti, and Smith (1993). Alternatively, one can forego the uniform pricing rule by using a dynamic bid-ask market. In such a market, each trader can post bids or offers, or accept any posted bid or offer; each transaction is a binding bilateral contract immediately upon acceptance. Dynamic markets with continual transactions preclude a uniform price but they have the advantage that they ensure impatience to trade. This impatience is borne of fear that profitable opportunities will be missed: when a demander posts a good bid, each supplier is eager to accept it before a competing supplier grabs it first. In such markets the volume of trade rises fairly steadily as the dispatch time approaches, and the accuracy of traders' predictions about the best bid and ask prices that will prevail at the close improves correspondingly.

Impatience to trade is one way to solve the fundamental problem of reliable price discovery. Any dynamic or iterative process provides a sequence of price signals to traders. If these interim prices are good predictors of the final prices that will prevail at the close, then they enable suppliers to make accurate judgments about which plants to operate and in which hours. In turn, early resolution about which plants to operate in each hour ensures stable convergence, since later iterations focus on the simpler task of finding the clearing prices for energy.

Price discovery is more problematic in the PX because no transactions occur until the close of the final iteration. Activity rules are needed to ensure that price discovery is reliable. Without activity rules, and with uniform pricing, no trader has any positive incentive to make serious bids or offers until the final iteration; and without serious bids and offers, the tentative clearing prices in early iterations are unreliable predictors of the final clearing prices. Indeed, any large trader has the opposite incentive: it withholds information about its own final offers in the early iterations, preferring instead to rely on others to provide such information contributing to price discovery. So in the absence of impatience of trade, activity rules are imposed in order to force all traders to reveal early some credible signals about the bids and offers they will tender in the final iteration.

In designing activity rules, the guiding principle is that they should be the least restrictive rules sufficient to assure reliable price discovery. Ideally, they impose no limit on the efficiency attainable at the close of the market. In particular, they should impose no significant restrictions or disadvantages on suppliers who elect to offer their actual costs. The only effect of the activity rules is to suppress gaming, or render it ineffective, by imposing constraints on revisions of offers during the iterative process. These constraints create increasingly strong incentives for cost-based offers. If the activity rules are successful, as the experimental evidence indicates they are, then suppliers learn that there is little to be gained by strategic bidding – it may delay convergence somewhat, but the final outcome is largely determined by cost-based offers in the closing iterations.

To preserve self-scheduling, the activity rules cannot be invasive; e.g., they cannot rely on any additional solicitation of reports about traders' private information. On the other hand, activity rules can be designed using the principle of “revealed preference.” By interpreting previous offers as reliable indicators of what is feasible and profitable for the supplier, constraints can be imposed on subsequent offers. As the auction progresses, these constraints narrow the supplier’s allowed strategies, until in the final iteration there is little room for offers that differ significantly from actual costs. Realistically, costs must be interpreted as opportunity costs rather than actual running costs, since each supplier also has opportunities to trade in other markets. In addition, opportunity costs must be interpreted in relation to market power. Activity rules cannot prevent a supplier from realizing the profit obtained when it offers the higher cost of the next plant along the aggregate supply function.

As a practical matter activity rules must be easily understood by traders, and simple to implement. The activity rules should be applied automatically: the portion of any submitted tender that violates the rules is discarded without any "negotiation" with the trader.

Activity rules are generally of two kinds. One kind pertains to the opening and closing of the auction, and the other pertains to the ways in which tenders can be revised or withdrawn from one iteration to the next. The rules treat demanders and suppliers symmetrically: the rules for demanders differ only by interpreting price decrements as price increments. To avoid confusion from separate phrasing regarding demanders and suppliers, I refer here only to the rules for suppliers.

I first describe the activity rules for the general case. This formulation is then developed in more detail for a practical implementation.

2. General Statement of the Activity Rules

The activity rules can be derived from a single formulation that is quite general in its application. To express this formulation succinctly, it is useful to interpret the tendered supply function as a bundle of contingent offers: each offer consists of a price for a particular increment of supplied energy. For example, one point on a tendered supply function might offer a price of \$23 per MWh for the 87th MWh delivered in the hour from 10 to 11 AM. Thus, I interpret a point (p,q,t) on the tender as offering the price p for the q-th increment of energy supplied in hour t.

The rule has three parts. In each iteration after the first, for each quantity increment included in the supply tender submitted in the first iteration:

1. The price cannot be increased.

2. The price can be decreased only if the new price is less than the clearing price in the previous iteration by at least a specified price

decrement (e.g., $1.00 or $0.10/MWh). We say in this case that the new price improves the previous clearing price.

3. The price cannot improve any previous clearing price not improved at the first opportunity.

Part 1 is a fundamental requirement for a competitive auction. Part 2's requirement that a price change improves the clearing price eliminates extraneous revisions. A minimum decrement avoids stalling the auction.

Part 3 is the key provision. To make it precise requires the following clarification: the "first opportunity" is the first iteration following an iteration in which the offered price exceeds the clearing price. For instance, if a supplier offers a price of $25 in iteration 1, in which the clearing price is $23, then iteration 2 is the first opportunity to improve this clearing price. If the supplier offers a price less than $23 in iteration 1 then for present purposes it has no obligation or "opportunity" in iteration 2 to improve the $23 clearing price obtained in iteration 1. Therefore, Part 3 imposes no restriction on suppliers who offer prices below the clearing price; in particular, these suppliers are not disadvantaged by refusing to improve the clearing price in the next iteration. However, among those suppliers who offer exactly the $23 clearing price there may be some whose offers are rejected according to the Rationing Rule. For these suppliers, iteration 2 is indeed the first opportunity to improve the previous clearing price.

With this clarification, Part 3 says the following, expressed via the example. Suppose the specified price decrement is $0.50. If in iteration 2 a supplier who offered $25 in iteration 1 does not improve iteration 1's clearing price of $23 then this is taken as *de facto* evidence that its cost increment for this quantity increment exceeds $22.50. Consequently, this supplier is precluded from offering a price equal to or less than $22.50 in any subsequent iteration. However, if the clearing price later rises above $23, say to $24 in iteration 5, then the supplier can in the next iteration 6 improve this clearing price by offering any price between $22.50 and $23.50 – but if it fails to do so then thereafter it cannot offer any price equal to or less than $23.50. Similarly, a supplier who offers exactly the clearing price of $23 in iteration 1 and is rationed, and then declines to improve its offer to a price at or below $22.50 in iteration 2, cannot offer a price in this range later.

The effect of Part 3 is to “freeze” any part of a supplier's tendered supply function for which there is presumptive evidence that its cost exceeds a previous clearing price. It is only frozen, not rejected irrevocably, because there remains the possibility that it is “thawed” if the clearing price rises sufficiently in some later iteration. Part 3 prevents a supplier from profiting by withholding supply until the final iteration.

This general form of the activity rule is not sufficient by itself. The reason is that it allows suppliers to offer very high prices in the first iteration. If demanders similarly offer very low prices in the first iteration then the auction gets off to a slow start due to the resulting gap between supply and demand. This is an inherent problem in all auctions; the usual way of correcting this deficiency is an Opening Rule that governs the first iteration.

The Competitive Process

Activity rules of this form produce a characteristic process of competition among suppliers. After each iteration the supply offers are divided into those that are infra-marginal, because their offered prices are less than the clearing price, and those that are extra-marginal, because their offered prices are more than the clearing price (or they are rationed). In the next iteration, each extra-marginal offer must improve the previous clearing price or forego all subsequent opportunities to offer lower prices – because it is frozen, perhaps permanently if later clearing prices remain below the previous clearing price. Thus, if the previous clearing price exceeds the supplier’s cost then the incentive to revise the offered price is quite strong, since this is the supplier’s last opportunity. However, when the offer is revised its position in the merit order (the offers ordered in terms of increasing cost to form the aggregate supply function) improves. This improvement relegates some previously infra-marginal offer to a later position in the merit order. The previously infra-marginal offer becomes extra-marginal, and the supplier who submitted it now faces a similar problem. The resulting process resembles a tug-of-war among the marginal suppliers to determine which offers will be accepted at the clearing price. This battle is resolved when the clearing price is driven down to the cost of some contenders, who then prefer to let their offers be frozen. The characteristic pattern is that in each iteration there are many bids and offers near the previous clearing price; but if one side of the market must be rationed, say the suppliers, then those whose offers are excluded and their costs are less, find it advantageous to reduce their prices.

3. An Implementation for the PX

This section describes a fairly complete set of procedural rules for the PX auction. These rules implement the main ideas elaborated in Section 2.

The Auction Process and the Bid Format

The auction can operate in a discrete or continuous mode. In each case there are 24 forward markets for delivery in the hours of the next day, and a clearing price is computed separately for each hourly market. In the version with discrete iterations, the auction operates in batch mode: all clearing prices are updated after each iteration. In the version with continuous market clearing, the arrival of each revised bid or offer prompts a revision of the clearing price in that market, which is then broadcast to all traders. These designs are associated with different formats for tenders. In the continuous version it suffices that each tender specifies a single price and a single quantity or interval for each hourly market. In the discrete version a tender is an entire demand or supply schedule for each hour, presumably in the form of a piecewise-linear function or a step function. In the following I do not address the continuous version, and focus instead on the discrete version.

In the discrete version, after each iteration the current tenders are used to calculate the clearing price for each hourly market independently. Each tender is specific to a particular hourly market, and consists of a piecewise-linear or step function that states the supply offered at each price. This function is interpreted as a bundle of contingent offers: each point (p,q,t) on the tender is an offer to deliver the quantity q in hour t at any price not less than p. Similarly, a step on the schedule offers a price p for any quantity within a corresponding min-max interval $[m,M]$.

The activity rules apply separately to each price-quantity pair (p,q) on the tender for a specific hour t. Thus, when checking the activity rules, no distinction is necessary regarding the exact form in which the tender is submitted: the same rules apply to tenders that are points, intervals, piecewise-linear, or step functions. For simplicity in the exposition, however, I assume that schedules are step functions.

Each tender is a binding bid or offer that remains in force until it is revised or ultimately rejected by the PX. A revised tender replaces all previous tenders for the same portfolio and hour. Except for those withdrawn or replaced, all tenders continue in force for the next iteration. At the close of the auction, those supply tenders with prices above the clearing price are rejected, with ties at the clearing price resolved by a Rationing Rule. The remaining offers are accepted, and each becomes automatically a binding contract, with the PX as the counter-party, for the offered quantity at the final clearing price.

The Opening Rule

The first part of the Opening Rule is simple:

Opening Rule (1): A new tender can be submitted only in the first iteration.

In particular, in each later iteration the only tenders allowed are revisions of ones submitted in the first iteration. This rule ensures that the maximum supply in each hourly market is revealed in the first iteration. This rule is essential for effective price discovery, else a trader could wait until the final iteration to submit its first tenders.

The second part of the Opening Rule is intended to get the auction off to a quick start.

Opening Rule (2): At its option, the PX can specify a seed price for the first iteration.

A seed price is an initial prediction of the final clearing price, which plays the role of the previous clearing price in applying the Exclusion and Revision Rules described below. Thus, after the first iteration that part of a supply tender that exceeds the seed price is frozen with the seed price as its Activation Price. The seed price can be based on expert judgment, or it could simply be the final clearing price in that hourly market the previous day or week.

The Exclusion and Revision Rules

I first describe these rules along the lines of Section 2 and then elaborate their motivation.

All tenders that were not withdrawn after previous iterations are automatically carried over to the current iteration. Based on the prior history of the auction, the steps on these tenders are divided into those that are frozen and those that are active: active steps can be revised, whereas frozen steps cannot. All steps are active in the first iteration. In each iteration after the first:

Exclusion Rule: A previously active step on a supply tender becomes frozen after the current iteration if its offered price was not revised to improve the previous clearing price, and in the previous iteration its offered price was above this clearing price – called its Activation Price. A frozen step cannot be revised. A frozen step becomes active again after an iteration in which the clearing price is higher than its Activation Price.

The Exclusion Rule operates as follows. If a tender's offered price for a particular step was less than the clearing price in the previous iteration then the supplier has no obligation to revise the offered price, but is not excluded from doing so. However, if its offered price exceeds the previous clearing price (or equal and the step is rationed), then its offered price must be revised to less than the previous clearing price, else it is frozen until the clearing price regains the previous level. For example, if the previous clearing price was $23 and the supplier now declines to offer a revised price less than $23 then this step cannot be revised again until after the clearing price rises above $23. As described in Section 2, the Exclusion Rule is based on the inference that refusal to improve the previous clearing price signals that the revised price would be insufficient to recover the supplier's cost.

The restriction that frozen steps cannot be revised is essential to reliable price discovery. Otherwise, a supplier could wait until the last iteration to revise, and in the meantime other traders would be getting no information about lower prices the supplier might be willing to offer. Thus, each tendered supply price that is above the clearing price in one iteration must be revised in the next iteration lest it thereafter be excluded from revisions until the clearing price rises again to comparable levels.

Revision Rule: An active step can be divided into two active steps with the same offered price. An active step can be revised only by offering a lower price that improves the previous clearing price. That is, the revised step must offer a new price for the same quantity interval that is less than the previously offered price, and less than the previous clearing price by at least the specified price decrement.

This particular phrasing of the Revision Rule is peculiar to the present supposition that each tender is represented as a step function. In this case, an active step corresponding to an offered price for an interval [m,M] of quantities can be revised by breaking it into two steps with intervals [m,k] and [k,M] . Then, one step is revised to offer a new price that improves the previous clearing price, and the second step is frozen. For the frozen step, the offered price is unchanged and its Activation Price is the previous clearing price.

The clearing price is computed using all steps on the current tenders, both frozen and active. This reflects the fact that even frozen steps remain binding offers to the PX. However, those steps that offer a higher price for a smaller quantity than another step are excluded from the merit order used for the computation, so they have no effect on the clearing price obtained.

It is important to realize that the price decrement (and a comparable price increment for demanders) is an important design parameter that can substantially affect the rate of convergence of the iterative process. In a worst-case scenario the clearing price moves by no more than the price decrement from one iteration to the next. The appropriate magnitude cannot be determined a priori; rather, it must be based on judgment, experience, and predictions about current supply and demand conditions, especially the price elasticities and variances of supply and demand. A practical procedure might start in iteration 2 with a large value, say $1.00/MWh, and then decrease it steadily in later iterations to a final value, say $0.20/MWh. However, experimental evidence indicates that a small decrement need not produce clearing prices closer to the theoretical clearing price. A large decrement has the advantage that it produces stronger pressure on suppliers to tender initial offers closer to actual costs: due to the large decrement, a price slightly above actual cost cannot be revised profitably, so a supplier must contend with the risk that a profitable opportunity will be missed.

Another important ingredient is the Rationing Rule. In a typical iteration there can be many offers at the clearing price, and if demand at that price is less than supply, then some of the supply steps must be rationed. The experimental evidence indicates that it is best to reject entire steps rather than allocate the marginal demand *pro rata* among the supply steps at the margin. This avoids a proliferation of subdivided steps and accelerates convergence.

The Withdrawal Rule

The following formulation assumes that after withdrawals the clearing prices are re-computed before the next iteration. Re-computing the clearing prices is desirable to ensure that other traders can take account of this information when revising their tenders for the next iteration.

Withdrawal Rule: After each iteration except the last, each supplier has the option to withdraw a tender entirely and irrevocably from any hourly market. The clearing prices are re-calculated after the withdrawal round. For the purposes of the Exclusion and Revision Rules and setting Activation Prices, these become the clearing prices for this iteration.

Withdrawals are allowed to enable a supplier to exit one or more markets when prices are insufficient to recover fixed costs, but after the final iteration an accepted tender cannot be withdrawn and the supplier is financially liable for delivery. It is clear that withdrawals cannot be revoked easily, else a supplier could withdraw until it re-enters in the final iteration. It might be argued that efficiency could be enhanced by allowing revocation of withdrawals if prices rise later. I have studied this problem but find revocation rules vulnerable to gaming. Within the strictures of the PX protocol, my solution is the Revision Rule, which is constructed explicitly to enable a supplier to offer tenders that cover its average costs. Consequently, my conclusion is that there is no need, and no easy prospect, to allow revocation of withdrawals. Withdrawals might be excluded (to prevent price manipulations followed by unpenalized withdrawals) but this would interfere with self-scheduling.

The Closing Rule

Closing Rule. All the hourly markets close simultaneously. They close automatically after any iteration in which no tender is revised, or a convergence criterion is satisfied.

Both theory and experiments show that the markets converge naturally, but the number of iterations required can exceed the time allowed. However, experiments show that there is little efficiency loss if the markets are closed after progress has slowed sufficiently. The primary criterion is a small ratio of active extra-marginal offers to those infra-marginal ones that would be displaced by another iteration, which signals that the current clearing price is close to the theoretical clearing price. Because quantities typically converge faster than prices, the efficiency loss from using a convergence criterion is likely small.

4. Conclusion

The purpose of activity rules is to encourage convergence to an efficient outcome by suppressing gaming. The rules proposed here are based on the principle of “revealed preference.” Essentially, a supplier’s refusal to improve a previous clearing price is taken as evidence that such a lower price would not recover its cost, and that therefore it can be prohibited from offering this price later. The resulting process forces suppliers at the margin to compete: each extra-marginal bidder improving the previous clearing price ejects some infra-marginal bidder who is thereby forced to reduce its offered price or forego any profit it might obtain. Each refusal freezes a step of the tender, until possibly the clearing price rises that high again later.

These rules are complemented by procedures for opening and closing the auction, and allowance for withdrawals. All tenders must be submitted at the opening to preclude a strategy of waiting until the final iteration that would impair price discovery. Withdrawals must be irrevocable and in any case withdrawals after the final iteration must be excluded.

The small-scale experimental tests conducted by Charles Plott (1997) indicate that, absent market power, these activity rules suppress gaming and drive the iterative process to nearly efficient prices and quantities in a moderate number of iterations.

Appendix: A Standard Set of Activity Rules

The following "standard" version of the activity rules was used for the experimental tests. This version is stated for supply tenders; symmetric rules apply to demand tenders. The tenders are assumed to be offered supply schedules that are step functions.

Tenders: Each step of each tender is a binding offer to trade at any price not less than the offered price. Each tender remains in force until it is withdrawn or validly revised by the trader, or rejected by the PX. A revised tender replaces the previous tender for the same portfolio. At the close of the auction, those steps with prices above the final clearing price are rejected; ties at the clearing price are resolved via the Rationing Rule: "first come, first served" based on the time stamp of each new or revised tender. The remaining steps are accepted, and each becomes automatically a binding contract, with the PX as the counter-party, for the tendered or rationed quantity at the final clearing price – except a step at the margin, for which only a portion of the offered quantity might be accepted.

Opening Rule: (1) A new tender can be submitted only in the first iteration. After the first iteration, the only valid tenders are those submitted in the first iteration and revised later. **(2)** The PX can specify a seed price to start the auction.

Exclusion Rule: An active step on a supply tender becomes frozen after the current iteration if its offered price is not validly revised to improve the previous clearing price, and in the previous iteration its offered price was above this clearing price – called its Activation Price. A frozen step cannot be revised. A frozen step becomes active again after an iteration in which the clearing price is higher than its Activation Price.

Revision Rule: An active step can be divided into two active steps with the same offered price. An active step can be revised only by offering a lower price that improves the previous clearing price. That is, the revised step must offer a new price for the same quantity interval that is less than the previously offered price, and also less than the previous clearing price by at least the specified price decrement.

Withdrawal Rule: After each iteration except the last, each supplier has the option to withdraw a tender entirely and irrevocably from any hourly market. If the clearing prices are re-calculated after the withdrawal round then for the purposes of the Exclusion and Revision Rules these become the clearing prices for this iteration.

Closing Rule: All hourly markets close simultaneously. They close automatically after an iteration in which no tender is revised, or a specified convergence criterion is met, or when the available time expires. The results of the final iteration become binding transactions with the PX at the final clearing price.

Notes

* Stanford Business School, Stanford CA 94305-5015 USA. Portions of the applied work reported here were funded by the California Trust for Power Industry Restructuring, and the basic theoretical work was conducted under a grant from the National Science Foundation.

References

McCabe, K, S. Rassenti, and V. Smith (1993), "Designing a Uniform-Price Double Auction: An Experimental Evaluation," Chapter 11 in D. Friedman and J. Rust (eds.), The Double Auction Market, Addison-Wesley.

Plott, C. (1997), "Experimental Tests of the Power Exchange Mechanism," Report to the California Trust for Power Industry Restructuring, March. (www.energyonline.com/wepex/reports/reports2)

Author's Address:
Stanford Business School, Stanford CA 94305-5015
Tel: 650-723-8620, Email: rwilson@stanford.edu