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Report to the California Trust For Power Industry Restructuring

ACTIVITY RULES FOR THE POWER EXCHANGE

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Executive Summary

In this condensation of my February 3 and 21 reports I summarize the proposed activity rules for the PX and their motivation. The key rule is 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 here by the Exclusion Rule, which "freezes" an offer that fails to improve the previous clearing price. When other routine procedural rules are included, the resulting activity rules perform well in experimental tests, as described in the March 3 reports by Charles Plott and me. A full set of activity rules is set forth in Appendix A, which constitutes my present recommendation.

Introduction

I was asked by the Trust to suggest activity rules for the power exchange (PX) within the structure defined by the PX Protocol. After their motivation is described in Section 1, the suggested rules are described in Section 2 and elaborated in Section 3; Appendix A provides a summary. This recommendation is subject mainly to the proviso that the software allows sufficiently many iterations within the time allowed for the PX, or failing that, the number of iterations can be reduced by invoking the remedies described in Section 3. Appendix B describes start-up provisions.

1. The Role of Activity Rules

Self-scheduling is a principal feature of the PX energy auction. Bids and offers are for delivered energy only. Transmission losses and fixed components such as start-up and no-load costs are absorbed by suppliers, who offer energy from portfolios of generation assets. There are several 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 Protocol, in which an iterative 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.

The role of withdrawals in the PX Protocol 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 CPUC order that in the PX all energy in a given hour is traded at the same price, exclusive of the zonal surcharges for transmission, and the policy decision 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.[*] Alternatively, one can forego the uniform pricing rule by using a dynamic bid-ask market. In such a market, during the week prior to dispatch, 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 preclude a uniform price but they have the advantage that they ensure impatience to trade. This is an impatience 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 price for energy.

Price discovery is more problematic in the PX Protocol because no transactions occur until the close of the final iteration. Activity rules are needed to ensure that price discovery is reliable. The issue is very simple: without activity rules, and with uniform pricing, no trader has any 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 signal 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 that suffice 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: the net effect is about the same as rounding up wild horses by driving them into the chute at the vertex of a V-shaped fence. If the activity rules are successful, as the preliminary experimental evidence indicates they are, then suppliers will learn that there is little to be gained by

[*] "Designing a Uniform-Price Double Auction: An Experimental Evaluation," Chapter 11 in Friedman and Rust (eds.), The Double Auction Market, Addison-Wesley, 1993.

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 here 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 running cost of the next plant in the merit order.

As a practical matter the activity rules must be easily understood by traders, and simple to implement. The activity rules should be applied automatically by the PX software: 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. All this is intended for the long run, ignoring the implementation problems that might affect the first weeks or months in 1998. I conclude with an alternative design that could be used in the initial weeks if necessary due to software limitations, as well as precautionary start-up provisions.

2. General Statement of the Proposed 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/MWh for the 107th MWh in the hour from 10 to 11 AM. Thus, I interpret a point (p,q) on the tender as offering the price p for the q-th increment of energy supplied.

The rule has three parts. In each iteration after the first, for each quantity increment included in the 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 averts 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 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 until later clearing prices rise above 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, it ejects from the merit order some previously infra-marginal offer, which now becomes extra-marginal, and that supplier now faces a similar problem. The resulting process resembles a tug-of-war among the marginal suppliers to determine which ones' offers will be accepted at the clearing price. This battle is resolved when the clearing price is driven down to the cost of some of the 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. A Proposed Implementation for the PX

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

The Auction Process and the Bid Format

I envision implementing the PX in three stages dictated by practical considerations. 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 Stage 3 (1999?) the auction can operate nearly continuously: as each revised bid or offer arrives, the clearing price in that market is updated and broadcast to all traders. In Stage 2 (mid-1998?) the auction operates in batch mode: all clearing prices are updated after each discrete iteration. In Stage 1 (early-1998?) it may be necessary to simplify further, allowing only withdrawals in several rounds after the first and only iteration; in particular, this excludes revisions of the tendered prices. Later I outline the Stage 1 default version, which copies parts of the existing VicPool design and might be implemented using the NordPool software.

These designs are associated with different formats for tenders. In Stage 3 it suffices that each tender specifies a single price and a single quantity or interval for each hourly market. In Stages 1 and 2 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 Stage 3 version, and focus instead on the earlier versions.

The Stage 2 version is conducted in discrete iterations. After each iteration, a clearing price for each hourly market is computed independently from the current tenders. 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) on the tender is an offer to deliver the quantity q in that hour 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 point (p,q) on the tender. 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. (Because the NordPool software used for the initial implementation currently depends on strictly increasing piecewise-linear schedules, the activity rules must be re-stated in the more complex form required by that restriction.)

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. This contract is an obligation for energy; the supplier remains liable also for the transmission surcharge, calculated as the difference between the zonal price and the PX 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 it is not evident that a small decrement will 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. Experiments as well as subsequent experience will provide guidelines about how to set the price decrement to ensure timely conclusion of the auction.

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, but it is not necessary if time is short.

- <u>Withdrawal Rule</u>: 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.

The purpose of withdrawals is to allow a supplier to exit one or more markets if 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, so I conclude for now that withdrawals must be monitored for predation under the general provisions for mitigation of market power.

The 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 can exceed the time allowed. However, the experiments and the simulations by London Economics have shown 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, and there are several subsequent markets before the actual dispatch, the efficiency loss from using a convergence criterion is likely small.

Failsafe Provisions

The motive for an iterative process is to allow suppliers to withdraw units whose fixed costs are not covered by the clearing prices for energy. This brings the risk that prices could be affected by withdrawals of large portfolios shortly before the final iteration. This subsection discusses some options that might be used to reduce this risk.

One option excludes withdrawals after the penultimate iteration, so that at least two iterations are available after the last withdrawal. A second option interprets the withdrawal or rejection of a tender as relevant only to transactions at the clearing prices. In this case, the tenders remain binding offers that the PX can accept at the tendered prices if this is deemed necessary according to some prudent criterion. A similar option is that the PX takes a position that it then clears in later markets; again there must be prudent guidelines.

The above options intervene in the energy market. An alternative relies on trades in the market for Inc/Dec options that occurs in the hour after the ISO's advisory re-dispatch. Because this market for trades among all the scheduling coordinators will function in any case to resolve price discrepancies among their markets, it is likely the best solution.

The Stage 1 Implementation

This subsection describes a simplified design can be used in January 1998 if there are impediments to on-time completion.

This design allows only a single iteration, but it allows multiple rounds for withdrawals. Thus each trader has a single opportunity, in the first and only iteration, to submit to each hourly market an entire demand or supply schedule of prices and quantities. Thereafter there are repeated rounds, each consisting of a determination of clearing prices followed by an opportunity to withdraw irrevocably from some hourly markets. That is, in each round the clearing prices are computed from those schedules not withdrawn previously; based on these clearing prices, each trader has an opportunity to withdraw its schedule irrevocably from any hourly market. Schedules cannot be revised. The auction closes after a round with no withdrawals.

A practical problem with this design is that the calculation of clearing prices might need to take account of ramping constraints. On the other hand each round can proceed quickly because the only communication required is a broadcast of hourly clearing prices followed by receipt of indications from some suppliers that they want to withdraw from some hours. If further simplification is necessary then demanders might be excluded from withdrawing: this would ensure that clearing prices converge monotonically, increasing from one round to the next.

4. Conclusion

The purpose of the 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 that improves the previous clearing price ejects some infra-marginal bidder who is thereby forced to reduce the offered price or forego any profit it might obtain. Each refusal freezes a step of the tender until 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 indicate that, absent market power, the activity rules suppress gaming and drive the iterative process to nearly efficient prices and quantities in a moderate number of iterations. The full-scale simulations by London Economics provide further support for these conclusions, and show that operationally feasible schedules are obtained. A principal topic for work in the next weeks is to refine the provisions for accelerating the auction, including the seed price used for a fast start and the convergence criterion used for an early close.

Appendix A

A Standard Set of Activity Rules

The following "standard" version of the activity rules is the one used for the experimental tests.* This version is stated for supply tenders; symmetric rules apply to demand tenders. The tenders are assumed to be schedules that are step functions; piecewise-linear schedules require modifications.

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.

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* The experiments used neither a seed price nor a convergence criterion.