Simultaneous Ascending Clock Auction for Gas Supply Contracts in Colombia

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Final Summary Report

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Abstract

The CREG has commissioned Market Analysis to specify the conceptual design and the structure of natural gas auctions to be implemented in Colombia. This project builds on previous work for the CREG by Cramton (2008) and Harbord (2010). The required tasks include the specification of: (i) the products or contracts to be sold in the auctions (Task 1); (ii) the overall conceptual design of the auction (Task 2); and (iii) the detailed auction rules (Task 3). This report summarizes the results of Tasks 1,2 and 3 of the project and specifies the rules for the auction design to be implemented, following extensive consultations with the industry.

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1 Introduction

The CREG has commissioned Market Analysis to specify the conceptual design and the structure of natural gas auctions to be implemented in Colombia. This project builds on previous work for the CREG by Cramton (2008) and Harbord (2010). The required tasks include the specification of: (i) the products or contracts to be sold in the auctions (Task 1); (ii) the overall conceptual design of the auction (Task 2); and (iii) the detailed auction rules (Task 3). The latter includes the auction bid functions, i.e. the demand and supply curves to be submitted by buyers and sellers in the auctions, the auction activity rules (if any), reserve prices (if any), the auction pricing and allocation mechanism, and any special rules required to address potential market power issues.

Our Task 2 report of 8 May 2011 described two possible auction designs: a simultaneous ascending clock auction, similar to that proposed in Cramton 2008, and a simultaneous sealed-bid ("assignment" or "product-mix") auction as described in Milgrom (2009) and Klemperer (2010). It also contained proposals for the auction products, frequency, minimum lot size and considered whether: (i) the products in the auctions should distinguish gas supplies by location, i.e. specify the field from which the gas is to be delivered, or whether all gas offered in the auctions could be treated as if it originated in the same location; and (ii) whether gas-fired power plants or upstream producers should be able to sell gas in the primary auctions in conditional firm contracts or options.

Following our consultations with the industry, our Task 3 report of 12 September 2011 specified the rules for the ascending clock auction to be implemented. This report summarizes the results of Tasks 1,2 and 3 of the project and specifies the rules for the auction design to be implemented, following further extensive consultations.

- Section 2 summarizes the main features of the proposed auction design.
- Section 3 describes the auction design and rules in greater detail.
- Annex A describes the auction "rulebook".

Our Task 3 report recommended "swap bids" for gas-fired power generators and producers in lieu of trading option contracts in the auctions. The reasons for this were described in that report and in our subsequent 15 September presentation to the industry in Bogota. In brief, including both Conditional Firm and Option contracts in the auctions creates combinations of products which are perfect substitutes for other products,

and introduces complementarities. For example, from the point of view of a distributor, purchasing a Conditional Firm contract plus an Option is equivalent to purchasing a Firm contract. Similarly, from the point of view of a power plant, purchasing an Option is equivalent to buying a Firm contract and selling a Conditional Firm contract. In both cases, since we have created perfect substitutes, we would expect large movements of demand away from some products and towards others on the basis of infinitesimal price differentials. We would also have introduced complements in the auction since, for a bidder who wishes to purchase firm gas, Conditional Firm contracts and options are perfect complements. As noted in our previous report, auctions work best if the products offered are substitutes from the point of view of the buyers. Market-clearing prices may not exist when goods are not substitutes, or there may be multiple, unrankable equilibria (see Milgrom 2007; Klemperer 2010).

An unfortunate consequence of this auction design decision, however, is that it limits producers sales of options (via swap bids) to the amount of gas sold under Conditional Firm contracts in exports to Venezuela or elsewhere. In addition, under the new standardized Firm and Conditional Firm contracts developed by the related consultancy (which are essentially 100% take or pay contracts), large amounts of gas purchased and resold by gas-fired power stations will become available in the secondary market at zero opportunity cost. This risks forcing secondary market prices down to unacceptably low levels and creating incentives for inefficient short-term consumption, investment and production decisions.

In light of this, we have decided that it would be better if producers were able to offer the entire array of standardized contracts in the auctions - i.e. Firm (F), Conditional Firm (CF) and Option (O) contracts. To avoid the issues described above however, such as the creation of perfect substitutes and complements, we propose a number of new restrictions on the auctions. First, gas-fired power plants will no longer have the opportunity to use "swap bids" in the auctions to buy Firm and sell Conditional Firm contracts.[1] Second, Option contracts would only be available to gas-fired power plants participating in the Firm Energy Market. All other auction participants would be limited to purchasing Firm and Conditional Firm contracts.

The only other change to the auction design is to better coordinate auction timing to the obligations of power plants in the firm energy market. Hence we recommend a change

[1] Gas-fired power stations will still be able to purcahse Firm contracts in the auctions, and resell Conditional Firm contracts in the secondary market on the Market Operator's platforms.

in the contract start dates from 1 January in each relevant year to 1 December in each relevant year.

A final issue which has yet to be resolved is the fixing of one of the prices in the Option contracts so that they can be sold in auctions. Option contracts include both a premium or daily "fee" and a per MBTUD gas price when the option is exercised. Suggestions for resolving this issue are discussed below.

2 Simultaneous Ascending Clock Auction for Gas Supply Contracts: Summary

Following consultations with the industry it was decided to develop an ascending clock auction design for long-term gas supply contracts in Colombia. Our Task 3 report proposed a single, simultaneous annual auction in which all fields and producers will be able to participate, to allow buyers to see all the options for long-term gas contracts, and to arbitrage across the substitute contracts, enhancing price formation and reducing transaction costs. The clock auction we propose would have the following features:

Products Standardized Firm (F), Conditional Firm (CF) and Option (O) contracts as developed by the related consultancy project,[2] of one and five year durations with the same start date and with products differentiated by field. The start date of the contracts would be approximately one year from the date of the auction. There was broad agreement in the comments received from the industry that Interruptible contracts should not be sold in the auctions, as they entail no commitment.[3]

Lot Size A minimum lot size of 100 MBTUDs, which is the quantity threshold for the nonregulated market, and no minimum bid unit (i.e. an allowable bid is for any quantity greater than the minimum lot size).

Participation of Producers Producers will sell Firm, Conditional Firm and Option contracts in the auctions and commit to the supply of each type of contract that they want to offer, differentiated by duration and field, and their reserve prices if any, before the auctions begin.

[2] *Consultancy for standardizing the contracts for supply and pipeline transportation of natural gas in Colombia,* Auctiononmics and FTI Consulting.

[3] Interruptible contracts can be traded instead on the Market Operator's secondary market trading platforms.

Participation of Gas-fired Power Plants Power plants participating in the electricity "firm energy market" will be able to purchase the Firm contracts and Option contracts offered by producers in the auctions (but not Conditional Firm contracts). Their demand for Option contracts will be limited to their corresponding potential firm energy obligations in the electricity market (OEFs), which will be reported to the auctioneer prior to the auction.

Other Buyers Other buyers will be able to purchase Firm and Conditional Firm contracts in the auctions, with their demands subject only to the standard activity rules specified below.

Information and Price Increments Before each auction, the auctioneer will announce the total supply of each product offered for sale and their reserve prices (if any).[4] At the end of every round the auctioneer will report: (i) the excess demand for each product; and (ii) the prices of all products for the next round, with price increments determined by the extent of excess demand for each product.

Activity Rule Bidders can switch demand freely during the auction between contracts differentiated by duration and fields (subject to the excess supply rule immediately below), but cannot increase total quantity demanded, i.e. demand can only decrease as prices rise.

Excess Supply Rule If one or more bidders wish to reduce demand for a product during the auction with the result that the product would be in excess supply, reductions in demand for the product will be accepted only up to the point where demand equals supply for that product.

Auction Termination Rule The auction terminates when there is no excess demand for any product, and each winning bidder is awarded quantities of each contract equal to its current demand and pays the current auction price for each contract won (except that marginal bidders may be rationed).

Contract Allocation Rules Since the auction products will not specify the seller, an allocation procedure will be implemented after the auction to assign particular contracts between buyers and sellers.

[4] If producers choose different reserve prices for a product, the auctioneer announces an increasing supply curve for that product.

No additional rules, such as rules to deal with situations where buyers might be deemed to have market power, have been found to be necessary. The following section describes the auction features and rules in more detail.

3 Auction Features and Rules

3.1 Auction Frequency, Products and Lot Size

The auctions will be held annually with the first auction held in October 2012. The auction products are standardized Firm, Conditional Firm and Option contracts as developed by the related consultancy project,[5] of one-year and five-year durations, with the same start date beginning approximately one year after the start of each auction. For example, contracts awarded in an auction held on 1 October 2012 will all have a start date of 1 December 2013.

Products are differentiated by field or delivery point (e.g. Guajira, Cusiana, and La Creciente). Hence there will be at most six products offered from each field (two F, two CF and two O contracts), and at most eighteen products offered in each auction, assuming the participation of producers from at most three fields.

There was broad agreement in the comments received from the industry that Interruptible contracts should not be sold in the auctions, as they entail no commitment.

Since the auction contracts or products will not specify the producer or seller, at the end of each auction, successful purchasers will be awarded contracts from particular sellers in a manner which minimizes the number of individual contracts awarded.

The minimum lot size in the auctions will be for 100 MBTUDs which is the quantity threshold for a nonregulated market. There is no minimum bid unit. That is, an allowable bid is for any quantity greater than the minimum lot size with no restriction on the number of decimal places in the bids.

3.2 Participation of Producers

Producers will sell F, CF and O contracts in the auction and must commit to the quantity supplied before the auction starts. Prior to each auction, each producer will announce the quantity of each type of contract, differentiated by field and duration, that it is willing to supply, and the minimum price it is willing to accept for each contract type (reserve

[5] *Consultancy for standardizing the contracts for supply and pipeline transportation of natural gas in Colombia,* Auctiononmics and FTI Consulting.

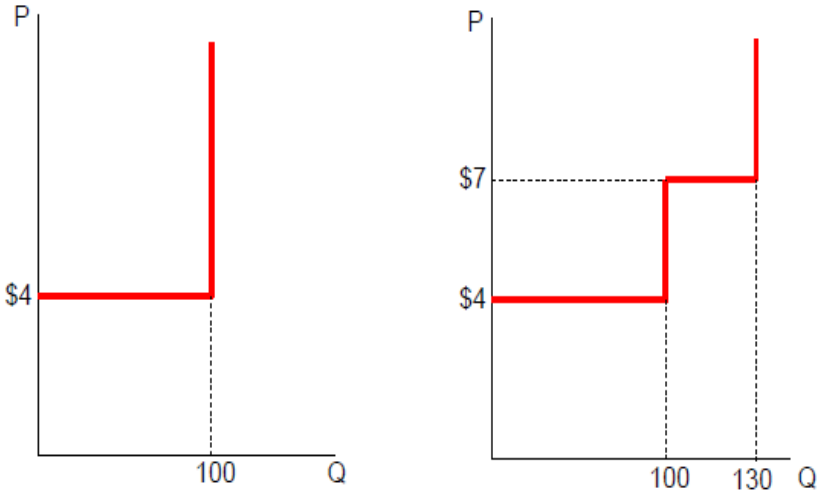

Figure 1: Supply Curve for Single Product

price).[6] Each producer is free to decide before the auction how to split its total supply between the various contracts type, with no requirement that quantity be offered for both one-year and five-year contracts of any type (F, CF or O), or in any particular proportion.

Assuming that producers are free to set their own reserve prices, then (in our view) a single reserve price should be set for each product for an individual seller. Different producers offering the same product from a given field might set different reserve prices, however. Figure 1 illustrates this.

In Figure 1, one producer offers 100 units of a particular contract (e.g. a one-year F contract from Cusiana) at a reserve price of $4. A second producer offers an additional 30 units of the same contract at a reserve price of $7. The aggregate supply curve for that contract is thus an upward-sloping step function. However each producer is limited to a single reserve price for its supply of each type of contract.

Option Contracts: Option contracts have two prices: a constant "premium", or option fee, paid daily or monthly and a gas price which applies when the option is "exercised". One possibility is to allow producers to specify the premium prior to the auctions (but this would lead to contracts differentiated by producer). A second possibility is to fix the

[6] Dominant or regulated producers' reserve prices may be subject to regulation or approval by the CREG. Since producers have used the regulated Guajira price to set their reserve prices in the past, one possibility would be to continue to use this benchmark, for example by setting reserve prices equal to αP where $\alpha < 1$ and P is the regulated Guajira price. A reasonable value for α might be 0.75 or 0.8.

MBTUD gas price at the level of the regulated Guajira price and allow the option fee to be determined by the auctions. On balance, we favour this latter proposal.

3.3 Participation of Gas-fired Power Plants

Gas-fired power plants in the interior of Colombia purchase large quantities of firm gas contracts in order to participate in the electricity firm energy market and receive "reliability" payments. Their demand for firm gas amounts to possibly 45% of the total available supply of gas in Colombia, and this gas must be resold by power plants to other consumers in Conditional Firm or other forms of interruptible or short-term contracts. Hence the gas-fired power plants would benefit from being able to purchase Option contracts in the auctions, relieving them of the need to first purchase and subsequently resell large amounts of gas in Firm contracts.

In order to achieve this, gas-fired power plants will be able to purchase both Firm contracts and Options in the auctions (but not Conditional Firm contracts). Purchases of Options will be limited to their corresponding potential firm energy obligations in the electricity market (OEFs), however. Power plants wishing to purchase Options in an auction will be required to report their maximum demands for Options to the auctioneer prior to the auction and this maximum demands must be less than their corresponding OEF obligation. Subject to this restriction, power plants demands for Firm contracts and Options will be subject to the activity rules described below.

3.4 Participation of Other Buyers

Buyers other than gas-fired power stations will be able to purchase Firm and Conditional Firm contracts in the auctions, with their demands subject only to the standard activity rules specified below. They will not be able to purchase Option contracts.

3.5 Information Policy and Price Increments

Before each auction, the auctioneer will announce the total supply of each product offered for sale and their reserve prices (if any). If producers choose different reserve prices for a product, the auctioneer actually announces a weakly increasing supply curve for that product. At the end of every round of the auction the auctioneer will report:

- the excess demand for each product; and

- the prices of all products for the next round, determined by the extent of excess demand.[7]

The price increment between rounds for each product is determined by the auctioneer according to the amount of excess demand on the contract, possibly taking account of the overall level of excess demand. Price increments should become smaller as the auction proceeds as excess demand decreases.

3.6 Auction Activity Rule

Because bidders' demands for one contract will typically depend on the prices of other contracts, to ensure an efficient allocation it is essential to allow bidders to "switch" their demands between the different contracts during the auction as prices change. For example, when the price of one contract increases compared to price of another contract, a bidder may want to reduce its demand on the first contract and increase its demand on the second. The auction mechanism should allow bidders to do this. Switching demand when relative prices change is natural when contracts are substitutes, as it is arguably the case with different types of gas supply contracts covering different periods of time and/or delivered at different locations.

Switching demand between the different contracts on sale will be allowed subject to an "activity rule" that controls a bidder's eligibility to make new bids on the various contracts during the auction. The activity rule creates pressure on bidders to bid actively from the start of the auction in a way that is consistent with the bidder's true preferences (e.g., avoiding "sniping"),[8] thus increasing the pace of the auction and the amount of information available to bidders during the auction.

The activity rule requires that a bidder cannot increase the total quantity demanded as prices rise: each bidder must bid a (weakly) downward sloping aggregate demand curve throughout the auction (see Activity Rule 1 in the Appendix). This activity rule imposes no restriction on the ability of the bidder to arbitrage across the contracts since the restriction is with respect to the aggregate quantity demanded, not the quantity for any individual contract. Hence, a bidder can switch demand between contracts from one

[7] Additional information about individual bidders' demand may also be announced to facilitate price discovery. However, more information also facilitates coordination among bidders and collusion.

[8] Sniping consists in a bidder only bidding at the very end of the auction for the goods it is interested in, in order to foreclose competing bids and/or to avoid revealing information about its true intention and valuations.

round to the other, so long as the total quantity it demands does not increase (subject to the rule to eliminate excess supply).

Example Consider a bidder that in one round bids for 1500 MBTUDs of gas contracts, say for 1000 MBTUDs 1-year Firm contracts from Guajira and 500 MBTUDs 5-year Conditional Firm contracts from Cusiana. In the next round, the bidders can bid for a total of 1500 MBTUDs or less of any type of gas contract from any field. So, for example, the bidder can bid for 1250 MBTUDs 5-year Firm contracts from Guajira and 250 MBTUDs 5-year Conditional Firm contracts from Cusiana. But, for example, the bidder cannot bid for 1600 MBTUDs 5-year Conditional Firm contracts from Cusiana.

3.7 Rule to Eliminate Excess Supply

Switching or demand reductions means that it is possible for a contract to go from excess demand to excess supply. Although the possibility of switching demand is essential to ensure an efficient allocation with substitute contracts, it may lead the auction to terminate with excess supply. This may happen, for example, when a bidder switches demand away from a contract or reduces demand on that contract at the end of the auction, causing total demand on that contract to be lower than supply.

A solution is to allow bidders to switch or reduce demand on a contract only up to the point at which demand equals supply for that contract (as suggested by Cramton, 2008). In this case: (i) a reduction in the quantity demanded of a contract is only accepted up to the point where demand equals supply for that contract and (ii) switches are similarly restricted to prevent excess supply. (See Activity Rule 2 in the Appendix.)

When more than one bidder wishes to reduce demand or switch away from a contract in one round, with the result that in aggregate demand is less than supply, then each bidder's demand reduction will be allowed in proportion to its size. For example, if in one round bidder A attempts to reduce demand by 100 MBTUDs and bidder B is by 50 MBTUDs, but the current excess supply is only 75 MBTUDs, then bidder A is allowed to reduce demand by 50 MBTUDs only and bidder B is allowed to reduce demand by 25 MBTUDs only, so that the excess supply is reduced to 0.

With these restrictions, once a contract has excess demand, it is guaranteed that the contract's full quantity will be sold.

3.8 Auction Termination, Contract Allocation and Rationing

Auction Termination Rules: The auction terminates when there is no excess demand on any product. Each winning bidder is awarded a quantity of each contract equal to its demand at the closing auction prices, and pays the auction price for each contract awarded. The only exception to this is, because of the rule to eliminate excess supply, marginal bidders may be rationed at the final auction prices.

Excess Supply Rules: The auction may end with excess supply for some or all products. This can occur if: (i) there is excess supply on individual products from the beginning of auction, but excess demand in aggregate; or (ii) there is excess supply in aggregate from the beginning of auction (although some products may be in excess demand when the auction opens).

If all products are in excess supply when the auction opens, then contracts are awarded at their reserve prices and demand allocated to producers in proportion to their offers to supply.[9] If some products are in excess demand and others in excess supply when the auction opens, then the auction proceeds as normal, increasing the prices of products in excess demand until the excess demand is eliminated. Products that remain in excess supply until the end of the auction are sold at their reserve prices, with demand allocated to producers in proportion to their offers to supply.

In cases (ii), price increments for products in excess demand should be minimal to allow bidders and opportunity to switch demand to products in excess supply.

Post-Auction Contract Allocation Rules: The auction products will not specify the seller of each contract. At the end of each auction, successful buyers will be awarded contracts from particular sellers in a manner which minimizes the number of individual contracts awarded.[10]

[9] For example, if Producer A offers 100 units of a product and Producer B 50 units, and demand is 100, then Producer A will be allocated 66.67 units and Producer B 33.33 units at the reserve prices.

[10] Cramton (2008) proposed that any buyer of a product would win quantity from all producers in proportion to the quantity offered by each seller. However, this could result in a very small purchaser needing to sign contracts with two or more producers in a given field (and subsequently nominating gas from multiple producers each day). It therefore appears preferable to assign buyers to producers in a manner which minimizes the number of contracts signed by each purchaser. In Annex A we suggest one possible method for doing so.

References

[1] Cramton, P. (2008) "Auctioning Long-Term Gas Contracts in Colombia," Bogota, 19 December.

[2] Harbord, D. (2010) "Upstream Issues in Colombian Gas Supply," Bogota, 12 April.

[3] Klemperer, P. (2010) "The Product-Mix Auction: a New Auction Design for Differentiated Goods," *Journal of the European Economic Association*, 8.

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[5] Milgrom, P. (2009) "Assignment Messages and Exchanges," *American Economic Journal: Microeconomics*, 1(2), 95-113.

[6] Milgrom, P., B. Broxson and G. S. Camacho (2011) "Consultancy for standardizing the contracts for supply and pipeline transportation of natural gas in Colombia," Bogota, 5 October.

A Auction "Rulebook"

Contracts. Before the start of the auction the auctioneer announces the contracts on sale in the auction, distinguished by type T ($T = F$ for firm, CF for conditional firm, and O for option), duration (d) and field (f).

Supply. Before the start of the auction:

- Each producer reports to the auctioneer the quantity of each F, CF and O contract that it is willing to supply, distinguished by duration (d) and field (f), and the reserve price for each contract. Let $S_{Ts}(f,d)$ be the quantity of T contracts ($T = F, CF, O$) from field f and of duration d offered by producer s. Let $r_{Ts}(f,d)$ be the reserve price for the T contracts from field f and of duration d supplied by producer s.

  Therefore, the total supply by producer s is

$$S_s = \sum\nolimits_f \sum\nolimits_d \left[S_{Fs}(f,d) + S_{CFs}(f,d) + S_{Os}(f,d) \right].$$

- Each power plant j reports to the auctioneer the maximum total quantity of O contracts that it is allowed to purchase D_{Oj}.

- The auctioneer announces the total supply of each contract on sale and the corresponding reserve prices.

  Let

$$S_T(f,d) = \sum\nolimits_s S_{Ts}(f,d), \quad T = F, CF, O$$

  be the total supply of T contracts from field f and of duration d, ignoring reserve prices. In general, if producers choose different reserve prices for identical contracts, then the aggregate total supply function of T contracts from field f and of duration d depends on the auction price p_T of that contract and is equal to

$$S_T(f,d,p_T) = \begin{cases} 0 & \text{if } p_T < r_{T1}(f,d) \\ S_{T1}(f,d) & \text{if } r_{T1}(f,d) \le p_T < r_{T2}(f,d) \\ S_{T1}(f,d) + S_{T2}(f,d) & \text{if } r_{T2}(f,d) \le p_T < r_{T3}(f,d) \\ \ldots & \ldots \\ \sum_{s=1}^{n-1} S_{Ts}(f,d) & \text{if } r_{Tn-1}(f,d) \le p_T < r_{Tn}(f,d) \\ \sum_{s=1}^{n} S_{Ts}(f,d) & \text{if } r_{Tn}(f,d) \le p_T \end{cases}$$

  where 1, ..., n indicates the producer with the lowest, ..., highest reserve price.

Auction Starting Prices. Before the start of the auction, the auctioneer announces the starting price of each contract which is equal to the lowest reserve price for that contract.

Demand/Bids. In each round of the auction, each bidder reports to the auctioneer its demand for each contract at the current auction prices. Only power plants are allowed to bid for O contracts. Power plants are not allowed to bid for CF contracts. Bidders can bid for any contract they are willing and allowed to acquire, subject to the activity rules. Let $D_{Tb}^{t}(f,d)$ be the quantity of contracts of type T from field f and of duration d that bidder b demands in round t of the auction.

Activity Rules. Bidders' demands are subject to the following activity rules.

Activity Rule 1A (*Non Power Plant Bidders*). For every non power plant bidder i and for every round t, it must be that

$$\sum\nolimits_{f}\sum\nolimits_{d}\left[D_{Fi}^{t}(f,d)+D_{CFi}^{t}(f,d)\right]\geq\sum\nolimits_{f}\sum\nolimits_{d}\left[D_{Fi}^{t+1}(f,d)+D_{CFi}^{t+1}(f,d)\right].$$

Activity Rule 1B (*Power Plants*) For every power plant j and for every round t, it must be that

$$\sum\nolimits_{f}\sum\nolimits_{d}\left[D_{Fj}^{t}(f,d)+D_{Oj}^{t}(f,d)\right]\geq\sum\nolimits_{f}\sum\nolimits_{d}\left[D_{Fj}^{t+1}(f,d)+D_{Oj}^{t+1}(f,d)\right],$$

and that

$$\sum\nolimits_{f}\sum\nolimits_{d}D_{Oj}^{t}(f,d)\leq D_{Oj}.$$

Activity Rule 2 (*No Excess Supply*) Suppose that in round t bidder b wants to reduce its demand for a contract of type T (from field f and of duration d) from $D_{Tb}^{t-1}(f,d)$ to K (either because bidder i wants to withdraw demand or because it wants to switch demand), but this would cause demand for that contract to be lower than supply — i.e.,[11]

$$K+\sum\nolimits_{k\neq b}D_{Tk}^{t}(f,d)<S_{T}^{t}(f,d),$$

where $S_{T}^{t}(f,d)$ represents the total supply of a contract of type T (from field f and of duration d) in round t.[12] Then bidder b's demand for contract T (from field f and of

[11] In the following expressions, we denote by k a generic bidder different from b.

[12] When producers choose different reserve prices for identical contracts, the supply of a contract of type T depends on the auction price of the contract in the current round t, say $p_{T}^{t}(f,d)$. For simplicity, we define $S_{T}^{t}(f,d)\equiv S_{T}(f,d,p_{T}^{t}(f,d))$.

duration d) in round t is constrained to be equal to

$$D_{Tb}^{t}(f,d) \equiv S_{T}^{t}(f,d) - \sum\nolimits_{k \neq b} D_{Tk}^{t}(f,d).$$

If in round t more than one bidder wants to reduce demand for the same contract of type T (from field f and of duration d) but this would generate excess supply for that contract, those bidders' demand reductions are rationed so as to prevent the emergence of excess supply. Specifically, let Ω be the set of bidders who want to reduce demand, and let $DR_{Tb}^{t}(f,d)$ be the amount of demand reduction requested by bidder b — i.e., bidder b is requesting to reduce its demand from $D_{Tb}^{t-1}(f,d)$ to $D_{Tb}^{t-1}(f,d) - DR_{Tb}^{t}(f,d)$. Then each bidder b who wants to reduce demand in round t is only allowed to do so by[13]

$$\frac{DR_{Tb}^{t}(f,d)}{\sum_{k\in\Omega} DR_{Tk}^{t}(f,d)} \left(D_{T}^{t-1}(f,d) - S_{T}^{t}(f,d)\right),$$

where $D_{T}^{t-1}(f,d)$ represents the total demand for contract T (from field f and of duration d) in round $t-1$. In other words, the demand of any bidder b who wants to reduce demand for contract T (from field f and of duration d) in round t is constrained to be equal to

$$D_{Tb}^{t}(f,d) \equiv D_{Tb}^{t-1}(f,d) - \frac{DR_{Tb}^{t}(f,d)}{\sum_{k\in\Omega} DR_{Tk}^{t}(f,d)} \left(D_{T}^{t-1}(f,d) - S_{T}^{t}(f,d)\right)$$

(while the demand of other bidders does not change from round $t-1$ to round t), so that the aggregate demand for contract T (from field f and of duration d) in round t is equal to its supply.

Information. At the end of every round of the auction, the auctioneer reports: (i) the excess demand for each contract — i.e., for a contract of type T from field f and of duration d,

$$\sum\nolimits_{b} D_{Tb}^{t}(f,d) - S_{T}^{t}(f,d);$$

and (ii) the new prices of all products for the following round, with price increments determined by the extent of excess demand for each product possibly taking account of the overall level of excess demand.

[13] In the following expressions, we denote by k a generic bidder who wants to reduce demand for contract T (from field f and of duration d) in round t.

Auction Termination Rule. The auction terminates when there is no excess demand on any product — i.e., in round t when

$$S_T^t(f,d) \geq \sum\nolimits_b D_{Tb}^t(f,d),$$

for every contract type T, field f and duration d. Every bidder b is awarded a quantity of contract type T from field f and duration d equal to $D_{Tb}^t(f,d)$ at a per-contract price equal to the auction price of that contract in round t.

Contract Allocation and Rationing Rules. At the end of the auction, successful buyers will be awarded contracts from particular sellers in a manner which minimizes the number of individual contracts awarded.

If the auction terminates with excess supply for a contract of type T from field f and duration d, then each producer s supplying that contract is rationed and its rationed supply $S_{Ts}^R(f,d)$ is

$$S_{Ts}^R(f,d) = S_{Ts}(f,d)\frac{D_T(f,d)}{S_T(f,d)},$$

where $S_{Ts}(f,d)$ is the supply by producer s for contracts T from field f and duration d at the end of the auction, $D_T(f,d)$ is the total demand for contracts T from field f and duration d at the end of the auction, and $S_T(f,d)$ is the total supply for contracts T from field f and duration d at the end of the auction.

Contract Allocation Minimization Rule. Consider a contract of type T from field f and duration d. At the end of the auction, order all bidders that have been awarded that contract from the largest to the smallest — i.e., from the one who demands the largest quantity of contract T from field f and duration d, to the one who demands the smallest quantity. Proceed by matching bidders demanding larger quantities with suppliers offering larger quantities. In other words, the first bidder signs a contract with the supplier with the largest quantity of contract T; and each successive bidder signs a contract with the supplier with the largest *residual* quantity of contract T (once contracts with previous bidders have been signed). Whenever there is a bidder who demands a quantity larger than the residual quantity of any supplier, match this bidder with smallest number of supplier that can satisfy its demand — i.e., the bidder signs contracts with the suppliers with the largest residual quantity of contract T, until all its demand is exhausted.

Use the same procedure for all types of contracts.