Simultaneous Ascending Clock Auction for Gas Supply Contracts in Colombia

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Task 3 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, as part of a Colombian "gas release" program. 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 contains the results of Task 3 of the project and specifies the rules for the auction design to be implemented, following consultations with the CREG and 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 CREG and with the industry, this report contains the results of Tasks 3 and specifies the rules for the ascending clock auction to be implemented.

- Section 2 summarizes the main features of the proposed auction design
- Section 3 describes the auction design and rules in greater detail
- Section 4 concludes
- Annex A describes special activity rules for "swap bids"
- Annex B describes the auction "rulebook"

2 Simultaneous Ascending Clock Auction for Gas Supply Contracts: Summary

Following consultations with the CREG and the industry it has been decided to develop an ascending clock auction design. We propose a single, simultaneous annual auction including all fields and producers, 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) and Conditional Firm (CF) contracts as developed by the related consultancy project,[1] of one and five year durations with the same start date and with products differentiated by field. The start date of the contracts would likely be 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.

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 only sell Firm 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,[2] before the auctions begin. Producers who have pre-sold Conditional Firm contracts (i.e. to Venezuela) will be able to offer the equivalent of "option" contracts in the auctions by using "swap" bids. They can do this by specifying before each auction the quantity they wish to offer. They will then be committed to supply an equivalent quantity of F contracts and be constrained to purchase equivalent quantities of either CF or F contracts during the auction.

Participation of Gas-fired Power Plants Power plants participating in the electricity "firm energy market" will be able to purchase the equivalent of "option" contracts in the auctions by using "swap" bids. They do so by first committing to sell certain quantities of specific types of CF contracts prior the auction (differentiated by field and duration) and will then be required to purchase equivalent quantities of F contracts or of CF contracts during the auction.

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).[3] 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.

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

[2] Producers' reserve prices may be subject to regulation or approval by the CREG.

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

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

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.

In the following section we describe the auction features and rules in more detail.

3 The Simultaneous Ascending Clock Auction

Section 3.1 describes the operation of the simultaneous ascending clock auction. Section 3.2 describes the auction features and rules in more detail.

3.1 General Description

In the ascending-clock auction bidding takes place in discrete rounds. In each round the auctioneer announces a new price for the product being sold, and each bidder submits a bid that specifies the quantity of the product that it is interested in acquiring at the announced price. When there are multiple contracts on sale in a simultaneous ascending-clock auction, ascending-clock auctions for each contract are run simultaneously, in order to allow bidders to compare the current prices for all products and observe the likely outcome of the auctions for all products, when deciding what quantity to demand of each contract. In each round the auctioneer announces one price for each of the contracts on sale and bidders indicate their demand for each product. After each round, the bidding results are posted, typically consisting of the total excess demand for each product at the current auction price. In subsequent rounds, the auctioneer increases the price of any product with excess demand but does not change the prices of products with no excess demand. The simultaneous ascending-clock auction terminates simultaneously for all

2009 auction for delivery at Cusiana

all contracts start in 2010; lot = 100 MBTU/d; price = US$/MBTU

Excess demand

No excess demand

Round	Supply	1-year	2-year	3-year	4-year	5-year	Total
		600	500	400	400	400	2300
1	Price	$5.00	$5.00	$5.00	$5.00	$5.00	
	Demand	1200	800	300	700	900	3900
2	Price	$5.50	$5.40	$5.00	$5.40	$5.60	
	Demand	1000	900	600	600	800	3900
3	Price	$5.90	$5.90	$5.50	$5.80	$6.00	
	Demand	900	900	600	550	750	3700
...							
9	Price	$7.60	$7.80	$7.70	$7.90	$7.90	
	Demand	600	500	450	400	400	2350
10	Price	$7.60	$7.80	$7.85	$7.90	$7.90	
	Demand	600	500	400	400	400	2300

Figure 1: Cramton Clock Auction Example

products, when there is no excess demand on any product. Each winning bidder is awarded a quantity of each product equal to its current demand (except that marginal bidders may be rationed) and pays the current auction price for each contract won.[4]

Figure 1 (taken from Cramton 2008) illustrates how the ascending clock auction works with many contracts. The top row indicates the supply offered for each of five contracts with delivery at Cusiana.[5] Each contract has the same starting price of $5. At this price, all but one of the contracts has excess demand; only the 3-year contract does not. As a result, for round 2, the price increases for all contracts, except the 3-year contract. Notice that the 1-year and 5-year contracts increase slightly faster, since these contracts had greater excess demand. In round 2, overall demand is the same as in round 1 at 3900 lots. No bidder has reduced demands. However, bidders did switch some quantity from one contract to others. As a result, at the end of round 2 there is excess demand for all contracts, and so all contracts have higher prices in round 3. By round 9, supply and demand balance for four of the five contracts; only the 3-year contract has excess demand. Thus, in round 10, only the 3-year contract has a higher price.

[4] For a more detailed description of the simultaneous ascending auction see our Task 2 report or Ausubel and Cramton (2004) and (2010).

[5] Cramton's example considers five different contract durations but the contracts could just as easily be differentiated by type, i.e. Firm and Conditional Firm contracts, or by field.

All contracts clear, and the auction ends, when the 3-year price reaches $7.85 and there is a reduction of 50, causing demand to match supply.

3.2 Auction Features and Rules

3.2.1 Auction Frequency, Products and Lot Size

The auctions will be held annually with the first auction held in December 2012. The auction products are standardized Firm and Conditional Firm contracts as developed by the related consultancy project,[6] of one-year and five-year durations, with the same start date beginning approximately one year after the start of each auction. That is, contracts awarded in the auction held in December 2012 will all have a start date of 1 January 2014.

Products are differentiated by field (e.g. Guajira, Cusiana, and La Creciente). Hence there will be at most four products offered from each field (two F and two CF contracts), and at most twelve 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. However in recent meetings we have heard opposite views expressed, so this issue remains open.

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.

3.2.2 Participation of Producers

Producers will only sell F 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 firm 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 price).[7] Each producer is free to decide before the auction how to split its total quantity of firm contracts by duration, with no requirement that quantity be offered for both one-year and five-year contracts, or in any particular proportion.

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

[7] The producers' reserve prices may be subject to regulation or approval by the CREG.

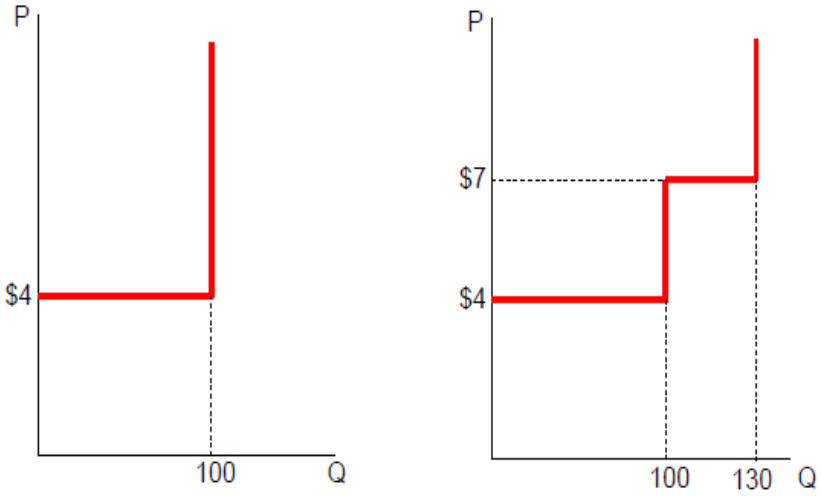

Figure 2: Supply Curve for Single Product

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 2 illustrates this.

In Figure 2, 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.

Producer swap bids Producers who have pre-sold CF contracts (e.g. to Venezuela) will be able to offer the equivalent of "option" contracts in the auctions, i.e. to sell gas when the spot market price for electricity exceeds the regulated "scarcity price" and hence they do not have to deliver gas under their CF contracts. A producer wishing to sell a quantity x of one type of option contract in the auction (specifying field and duration), can do so by using an equivalent "swap" bid, similar to those described for gas-fired power plants immediately below. Specifically, the producer commits to sell a quantity x of one type of F contract (specifying field and duration) before the auction and then, during the auction, it buys an equal quantity x of either F contracts or CF contracts, or both, from the same field and of equal duration as the F contract that it committed to sell.

Notice that, by selling an F contract and buying a CF contract, the producer is actually selling an "option" contract in the auction, at a price equal to the difference between the price

of F contract and the price of CF contract. By contrast, if the producer buys F contracts in the auction, it reduces its supply of option contracts, which it may want to do if CF contracts become too expensive compared to F contracts.[8]

Example Consider a hypothetical producer who has a total firm production available of 400 GBTUDs and sells 100 GBTUDs in CF contracts to Venezuela before auction. The producer then has 300 GBTUDs available in F contracts to place in the auction and 100 GBTUDs in Options, or "swap" bids. To perform the swap bid, the producer offers to sell an additional 100 GBTUDs in F contracts and to purchase 100 GBTUDs in CF contracts. If successful, the producer will have sold 400 GBTUDs in F contracts in the auction, and purchased 100 GBTUDs in CF contracts, exactly as needed to supply Venezuela. This is equivalent to selling 300 GBTUDs of F contracts in Colombia; 100 GBTUDs of CD contracts to Venezuela; and 100 GBTUDs of options in Colombia. Alternatively, the producer is free to "buy back" up to 100 GBTUDs in F contracts in the auction to cancel the transaction.

3.2.3 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 make their purchases of Firm contracts in the auctions contingent upon selling equal quantities of Conditional Firm contracts, to avoid "execution risk".

In order to achieve this, gas-fired power plants will be able to participate in the auctions as both buyers and sellers, offering to purchase Firm contracts from producers whilst simultaneously offering to sell Conditional Firm contracts in a "swap" bid.[9] Specifically, before each auction, a power plant can commit to sell a quantity x of one type of Conditional Firm contract (specifying field and duration) and then, during the auction, to purchase an equal quantity x (or greater) of either Firm contracts or Conditional Firm contracts, or both, from the same field and of equal or longer duration as the Conditional Firm contract that it has committed to sell.[10]

The power plant decides which type of contract to buy in the auction depending on the relative prices of the two contract types. If: (i) the power plant purchases x Conditional Firm

[8] Special "activity" rules for these "swap" bids are described in more detail in Annex A.1 below.

[9] It is possible that other types of agents may wish to offer "swap" bids in the auctions. There would appear to be no reason to prevent them from doing so, although our discussion focuses on gas-fired power plants.

[10] There is no need for power plants to specify reserve prices for the conditional firm they offer since they will be able to "buy back" all or part of the quantity of conditional firm offered during the auction.

contracts during the auction, then the transaction cancels out with the commitment to sell Conditional Firm contracts, and the power plant's net supply of Conditional Firm contracts is 0 (although the power plant can still buy an additional quantity of Firm gas contracts, of course); or (*ii*) if the power plant buys x or more Firm contracts (and does not buy Conditional Firm contracts), then it performs the intended transaction of buying x Firm contracts and simultaneously selling x Conditional Firm contracts.[11]

Notice that the transaction of buying Firm and simultaneously selling Conditional Firm contracts is equivalent to buying an "option" that allows the power plant to obtain gas when the spot market price for electricity exceeds the regulated "scarcity price". The price of the "option" is equal to the difference between the price of Firm contracts purchased and the price of Conditional Firm contracts sold.

Notice also that the commitment to sell Conditional Firm contracts does not impose any real restraint to a bidder's strategy in the auction. For example, suppose that a power plant does not want to buy Firm contracts if they are more expensive than a price P, regardless of the price at which it can sell Conditional Firm contracts. Then the power plant simply has to buy x Conditional Firm contracts in the auction if the price of Firm contracts is above P (which is perfectly consistent with substitute preferences), and hence cancel its commitment to sell x Conditional Firm contracts before the auction.

3.2.4 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.[12]

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.

[11] The "activity" rules for these swap bids are described in more detail in Annex A.2 below.

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

3.2.5 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"),[13] 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 round to the other, so long as the total quantity it demands does not increase (subject to the rules to eliminate excess supply and the activity rules for swap bids that are described below).

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.

[13] 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.

3.2.6 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, thus 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 4 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.

Intraround bidding: A related problem is that, because the price increments between rounds are discrete, in the ascending auction the price of a contract may increase above its market-clearing level, thus causing the auction to terminate with excess supply. The risk of generating excess supply due to discrete price increments can be (partially) solved by using "intraround" bids, which allows bidders to express their demands for each contract at each price between the start-of-round price and the end-of-round price chosen by the auctioneer, in any round (Ausubel and Cramton, 2004). Intraround bidding is an effective method for a bidder who wants to reduce its demand for a contract to indicate the precise price at which it is willing to do so, and hence it is indifferent between doing it or not. If this reduction causes the emergence of excess supply for the contract, the auctioneer can choose an auction price equal to the that precise price indicated by the bidder, and ration the bidder so as to equalize the total demand and supply for the contract.

Notice, however, that intraround bidding is less helpful for a bidder who wants to switch

demand between contracts (or in general when the price at which it wants to reduce its demand for one of the contracts also depends on the prices of other contracts). The reason is that, with intraround bids, a bidder cannot condition its bid for one of the contracts on the prices of other contracts; hence, it cannot indicate at what precise *relative* price it wants to switch demand, and hence it is indifferent between doing it or not.

Another similar partial solution to prevent the auction from terminating with excess supply due to discrete price increments is for the auctioneer to reduce the contracts' prices to the levels of the next-to-last round when the auction terminates with excess supply, and allow bidders to make best and final bids. Given those bids, the auctioneer can choose the precise contract prices that equalize supply and demand. Basically, this is equivalent to allowing bidders to make intraround bids only in the last round of the auction.

We are not necessarily recommending the introduction of intraround bidding for the Colombian gas contract auctions.

3.2.7 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.[14] 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.

[14] For example, if Producer 1 offers 100 units of a product and Producer 2 50 units, and demand is 100, then Producer 1 will be allocated 66.67 units and Producer 2 33.33 units at the reserve prices.

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.[15]

4 Conclusions

We have described the rules and procedures for implementing a simultaneous ascending clock auction for long-term gas supply contracts in Colombia. The auction design proposed is standard except for the inclusion of two types of "swap" bids for gas-fired power plants and for producers. Allowing gas-fired power plants to purchase Firm contracts and simultaneously sell Conditional Firm contracts in the auctions is important for two reasons: (i) it mitigates the risk for power plants of purchasing Firm contracts before knowing either the quantity of Conditional Firm contracts which will be demanded, or at what price; and (ii) it allows other buyers, such as distributors and industrial customers, to see the price of Conditional Firm contracts in the auction and substitute between Conditional Firm and Firm contracts accordingly.

If producers have sold quantities of Conditional Firm contracts before the auction, it is also efficient to allow them the opportunity to sell the equivalent quantities of "option" contracts in the auction. We propose to accommodate this by allowing producers to perform a type of "swap" bid similar to that suggested for gas-fired power plants. The reason for this is that introducing 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).

[15] 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.

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A Activity Rules for Swap Bids

A.1 Producers' Swap Bids

Producers who want to sell option contracts of a particular type (specifying field and duration) are allowed to buy either Firm or Conditional Firm contracts of the same type during the auction, but only up to the quantity of option contracts that they have offered to sell — i.e., only up to the quantity of Conditional Firm contracts sold to Venezuela prior to the auction. This is to prevent producers from using the possibility of a swap bid to strategically reduce the supply of gas and create scarcity, by buying back the Firm contracts that they committed to sell.

When a producer indicates that it wants to sell a quantity x of a particular type of option contracts before the auction, during the auction its total demand for Firm and Conditional Firm contracts from the same field and of equal duration is constrained to be exactly equal to x. Specifically, let $S_O(f,d)$ be the quantity of option contracts from field f and of duration d that the producer wants to sell. Let $D_F^t(f,d)$ be the quantity of Firm contracts from field f and of duration d that the producers demands in round t of the auction, and let $D_{CF}^t(f,d)$ be the quantity of Conditional Firm contracts from field f and of duration d that the producers demands in round t of the auction. In any auction round t, it must be that

$$D_F^t(f,d) + D_{CF}^t(f,d) = S_O(f,d).$$

A.2 Power Plants' Swap Bids

An additional activity rule is necessary to ensure that a power plant who wants to perform a swap bid for Firm and Conditional Firm contracts does not end up selling Conditional Firm contracts that it does not own (because of its commitment before the auction). Therefore, when a power plant commits to sell a quantity x of one type of Conditional Firm contracts before the auction, during the auction its total demand for Firm and Conditional Firm contracts from the same field and of equal or longer duration is constrained to be greater than or equal to x.

Specifically, let $S_{CF}(f,d)$ be the quantity of Conditional Firm contracts from field f and of duration d that the power plant commits to sell before the auction. Let $D_F^t(f,l)$ be the quantity of Firm contracts from field f and of duration l that the power plant demands in round t of the auction, and let $D_{CF}^t(f,l)$ be the quantity of Conditional Firm contracts from field f and of duration l that the power plant demands in round t of the auction. It must be that

$$\sum\nolimits_{l \geq d} \left[D_F^t(f,l) + D_{CF}^t(f,l) \right] \geq S_{CF}(f,d), \quad \forall t.$$

Of course, this rule restrains a power plant's ability to switch demand between contracts and reduce demand on certain contracts during the auction.

B 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,CF), duration (d) and field (f).

Supply: Before the start of the auction

- Each producer reports to the auctioneer the quantity of each F contract that it is willing to supply, distinguished by duration (d) and field (f), and the reserve price for each contract. Let $S_{Fi}(f,d)$ be the quantity of F contracts from field f and of duration d offered by producer i (which also includes the quantity of F contracts that the producer supplies in order to perform a swap bid — i.e., its supply of option contracts). Let $r_{Fi}(f,d)$ be the reserve price for the F contracts from field f and of duration d supplied by producer i.

  Therefore, the total supply of F contracts from field f by producer i is

$$S_{Fi}(f) = \sum\nolimits_d S_{Fi}(f,d),$$

  and the total aggregate supply of F contracts from field f is

$$S_F(f) = \sum\nolimits_i \sum\nolimits_d S_{Fi}(f,d).$$

- Each producer also reports the quantity of each option contract that it is willing to sell. Let $S_{Oi}(f,d)$ be the maximum quantity of option contracts from field f and of duration d that producer i is willing to sell. $S_{Oi}(f,d)$ must be equal to the quantity of CF contracts from field f and of duration d that producer i sold to Venezuela; and it must be that $S_{Oi}(f,d) \leq S_{Fi}(f,d)$.

- Each power plant reports to the auctioneer the quantity of each CF contract that it is willing to supply, distinguished by duration (d) and field (f). Let $S_{CFi}(f,d)$ be the quantity of CF contracts from field f and of duration d supplied by power plant i.

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

  Let

$$S_F(f,d) = \sum\nolimits_i S_{Fi}(f,d)$$

  be the total supply of F 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 F contracts from field f and of duration d depends on the auction price p of that contract and is equal to

$$S_F(f,d,p) = \begin{cases} 0 & \text{if } p < r_{F1}(f,d) \\ S_{F1}(f,d) & \text{if } r_{F1}(f,d) \leq p < r_{F2}(f,d) \\ S_{F1}(f,d) + S_{F2}(f,d) & \text{if } r_{F2}(f,d) \leq p < r_{F3}(f,d) \\ ... & ... \\ \sum_{i=1}^{n-1} S_{Fi}(f,d) & \text{if } r_{Fn-1}(f,d) \leq p < r_{Fn}(f,d) \\ \sum_{i=1}^{n} S_{Fi}(f,d) & \text{if } r_{Fn}(f,d) \leq p \end{cases}$$

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

Let

$$S_{CF}(f,d) = \sum\nolimits_i S_{CFi}(f,d)$$

be the total supply of CF contracts from field f and of duration d.

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. Producers can bid for F and CF contracts from field f and of duration d only if they are supplying option contracts from field f and of duration d. Other bidders can bid for any contract they are willing to acquire, subject to the activity rules. Let $D_{Tj}^t(f,d)$ be the quantity of contracts of type T from field f and of duration d that bidder j demands in round t of the auction.

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

Activity Rule 1 (*Decreasing Demand*) For every bidder j and for every round t, it must be that

$$\sum\nolimits_f \sum\nolimits_d \left[D_{Fj}^t(f,d) + D_{CFj}^t(f,d)\right] \geq \sum\nolimits_f \sum\nolimits_d \left[D_{Fj}^{t+1}(f,d) + D_{CFj}^{t+1}(f,d)\right].$$

Activity Rule 2 (*Producers' Swap Bid*) For every producer j, every contract (from field f and of duration d) and every round t, it must be that

$$D_{Fj}^t(f,d) + D_{CFj}^t(f,d) = S_{Oj}(f,d).$$

Activity Rule 3 (*Power Plants' Swap Bid*) For every power plant j, every contract and every round t, it must be that

$$\sum\nolimits_{l \geq d} \left[D_{Fj}^t(f,l) + D_{CFj}^t(f,l)\right] \geq S_{CFj}(f,d).$$

Activity Rule 4 (*No Excess Supply*) If in round t bidder i wants to reduce its demand for a contract of type T (from field f and of duration d) from $D_{Ti}^{t-1}(f,d)$ to K (either because bidder i wants to withdraw demand or because it wants to switch demand) but[16]

$$K + \sum\nolimits_{j \neq i} D_{Tj}^{t}(f,d) < S_{T}^{t}(f,d),$$

then bidder i's demand for contract T (from field f and of duration d) in round t is constrained to be equal to

$$D_{Ti}^{t}(f,d) \equiv S_{T}^{t}(f,d) - \sum\nolimits_{j \neq i} D_{Tj}^{t}(f,d).$$

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 $DR_{Ti}^{t}(f,d)$ be the amount of demand reduction requested by bidder $i \in \Omega$ — i.e., bidder i is requesting to reduce its demand to $D_{Ti}^{t-1}(f,d) - DR_{Ti}^{t}(f,d)$. Then each bidder $i \in \Omega$ is only allowed to reduce demand by

$$\frac{DR_{Ti}^{t}(f,d)}{\sum_{j\in\Omega} DR_{Ti}^{t}(f,d)} \left(\sum\nolimits_{j\in\Omega} D_{Tj}^{t-1}(f,d) + \sum\nolimits_{k\notin\Omega} D_{Tk}^{t}(f,d) - S_{T}^{t}(f,d) \right).$$

In other words, bidder i's demand for contract T (from field f and of duration d) in round t is constrained to be equal to

$$D_{Ti}^{t}(f,d) \equiv D_{Ti}^{t-1}(f,d) - \frac{DR_{Ti}^{t}(f,d)}{\sum_{j\in\Omega} DR_{Ti}^{t}(f,d)} \left(\sum\nolimits_{j\in\Omega} D_{Tj}^{t-1}(f,d) + \sum\nolimits_{k\notin\Omega} D_{Tk}^{t}(f,d) - S_{T}^{t}(f,d) \right),$$

so that the aggregate demand for contract T (from field f and of duration d) in round t is equal to

$$\sum\nolimits_{i\in\Omega} D_{Ti}^{t}(f,d) + \sum\nolimits_{k\notin\Omega} D_{Tk}^{t}(f,d) = S_{T}^{t}(f,d).$$

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,

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

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..

[16] 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 $S_{T}^{t}(f,d) \equiv S_{T}\left(f,d,p_{T}^{t}(f,d)\right)$.

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

$$S_T^t(f,d) \geq \sum\nolimits_i D_{Ti}^t(f,d),$$

for every contract type T, field f and duration d. Every bidder i is awarded a quantity of contract type T from field f and duration d equal to $D_{Ti}^t(f,d)$ 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 i supplying that contract is rationed, so its rationed supply $S_{Ti}^R(f,d)$ is given by

$$S_{Ti}^R(f,d) = S_{Ti}^t(f,d)\frac{D_T^t(f,d)}{\sum_j S_{Tj}^t(f,d)}.$$

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