Second Review of Firm Energy Auctions in Colombia*

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1 Introduction

In 2006 Colombia introduced a new regulatory scheme to ensure the reliability of the long-term supply of electricity, and in particular to guarantee that there is always sufficient capacity available to meet peak demand during El Niño periods when hydro resources are significantly reduced.[1] The scheme allocates Firm Energy Obligations (OEFs) to new and existing generating plant in order to guarantee a sufficient long-run supply of firm energy at prices determined in competitive auctions. OEFs are "option contracts" that commit generating companies to supply contracted amounts of energy at a predetermined Scarcity Price whenever the spot price in the electricity market exceeds the Scarcity Price.[2] They receive the spot price for any additional generation above their firm energy obligation, and pay a penalty if they cannot meet their firm energy obligation, equal to the difference between the spot price and the scarcity price on the OEF quantity not met in any hour.

In return for agreeing to supply at the Scarcity Price, generators allocated OEFs receive a fixed annual option fee (the firm energy price, or Cargo por Confiabilidad) for the amount of energy contracted. This option fee makes an important contribution to the recovery of fixed costs for generating plants, especially thermal plants that sell very little energy in normal conditions

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[1] See Cramton and Stoft (2007), Harbord and Pagnozzi (2008) and Robinson, Riascos and Harbord (2012) for more detailed descriptions.

[2] The electricity Scarcity Price is established by the CREG and updated monthly based on the variation of the Fuel Price Index. In March 2012 it was approximately US$248/MWh. The Scarcity Price has a double purpose. On the one hand, it indicates the time when the different generation units or plants will be required to fulfill their firm energy obligations, which happens when the Spot Price exceeds the Scarcity Price; on the other hand, it is the price at which this energy will be paid.

(such as the CCGT plants in central Colombia that generate infrequently outside of El Niño periods).

The maximum amount of firm energy that a generator may offer in a firm energy auction is known as its ENFICC (Energía Firme para el Cargo por Confiabilidad). ENFICC refers to the amount of energy a generator of a given type can reliably and continually produce during periods when hydro generating capacity is at a minimum.[3] Table 1 shows the typical ENFICCs for different generation technologies in Colombia as a percentage of a plant's effective net capacity (CEN).[4,]

Table 1: ENFICC % for different technologies

Technology	**Typical ENFICC**
Hydro with storage	55%
Hydro without storage	30%
Coal	90 - 95%
Natural Gas	93%
Fuel Oil	88%
Wind	6%

The first OEF auctions were held in May and June 2008 and allocated OEFs for periods of up to twenty years beginning in December 2012. As a result some 9,000 GWh per year of OEFs were allocated to new resources, along with 62,860 GWh per year allocated to existing generating plant at an auction-determined "option" price of \$13.998/MWh. Existing generating plant will receive this option fee until December 2015, while new resources are guaranteed the fee for up to twenty years. Auctions are held whenever the CREG estimates that the demand for energy in future years cannot be covered during scarcity periods by the energy production of existing generation resources and any planned new resources that will enter into operation. To quote the CREG, "*this new scheme aims to ensure the reliability in the supply of energy in the long-run at efficient prices.*"

The first firm energy auction, held in May 2008, was a descending clock auction (DCA) for resources with planning periods of less than 4.5 years. About 3009 GWh per year of OEF's were allocated to new resources in this auction, including 1,117 GWh from new coal plant and 1,678 GWH from new gas-fired generation plant at an auction-determined option fee of \$13.998/MWh. Table 2 below shows the results of this auction.[5]

[3] See CREG RESOLUCIÓN 071 DE 2006: "Energía Firme para el Cargo por Confiabilidad (ENFICC): Es la máxima energía eléctrica que es capaz de entregar una planta de generación continuamente, en condiciones de baja hidrología, en un período de un año."

[4] See Robinson, Riascos and Harbord (2012) for a more detailed discussion of the calculation of ENFICC in the Colombian electricity market.

[5] The entry dates for each of these plants has been moved forward.

Table 2: Outcome of 6 May 2008 DCA (Gwh/Año)

Project	Company	Entry Date	Type	OEF
Gecelca III	Gecelca	Dec 2012	Coal	1117
Amoyá	Isagen	Dec 2012	Hydro	214
Termocol	Poliobras	Dec 2012	Liquid fuels	1678

The second auction (the "GPPS auction") held in June 2008, was for resources with longer planning periods, and allocated 6280 GWh per year to new hydro plants, as shown in Table 3.[6]

Table 3: Outcome of 13 June 2008 GPPS Auction (Gwh/Año)

Project	Company	Entry Date	Type	OEF	ENFICC
Pescadero Ituango	EPM	Dec 2018	Hydro	1085	8563
Sogamoso	Isagen	Dec 2014	Hydro	2350	3791
El Quimbo	Emgesa	Dec 2014	Hydro	1650	1750
Porce IV	EPM	Dec 2015	Hydro	961	1923
Miel II	Promotora	Dec 2014	Hydro	184	184
Cucuana	EPSA	Dec 2014	Hydro	50	50

Firm energy auctions were held again in December 2011 and January 2012. The December auction was again a descending clock auction for resources with planning periods of less than 4 years, and allocated of 3,700 GWh of OEFs to five new generation projects, with a total capacity of 575 MW (Table 6). The option fee (firm energy price) resulting from this auction was $US15.7/MWh.[7] Table 4 summarizes the results of this auction.

Table 4: Outcome of December 2011 DCA Clock Auction (Gwh/Año)

Project	Company	Entry Date	Type	OEF
Gecelca 32	Gecelca	Dec 2015	Coal	1971
Tasajero II	Termotasajero	Dec 2015	Coal	1332
Carlos Lleras Restrepo	Hidroelectrica del Alto Porce	Dec 2015	Hydro	200
San Miguel	La Cascada S.A.S.	Dec 2015	Hydro	123
Ambeima	Empresa Energia Los Andes	Dec 2015	Hydro	75

The January 2012 GPPS auction for resources with longer planning periods allocated 6,987 GWh per year to new resources from December 2017, as summarized in Table 5.

[6] Construction of Porce IV has been cancelled.

[7] This firm energy price will be paid to existing resources from December 2015 until a new price is set by a subsequent auction, and to new plant allocated OEFs in the auction for up to 20 years beginning in December 2015.

Table 5: Outcome of January 2012 GPPS Auction (Gwh/Año)

Project	Company	Entry Date	Type	OEF	Price
Pescadero Ituango	EPM	Dec 2021	Hydro	3482	15.7
Sogamoso	Isagen	Dec 2016	Hydro	1440	15.7
Porvenir II	Producción de Energía	Dec 2018	Hydro	1445	11.7
Termonorte	Termonorte	Dec 2017	Thermal	619	14.9

The purpose of this report is to consider the results of two most recent auctions and suggest useful changes to the auction formats, taking account of the 2008 experience, described in detail in Harbord and Pagnozzi (2008). Section 2 describes the auction history in more detail. Section 3 considers the issues which have arisen to date and contains proposals for improving future auction performance. Section 4 summarizes our recommendations.

2 The OEF Auctions

As noted above, OEF auctions were held in May and June 2008, and later in December 2011 and January 2012. The first auctions in each case were descending clock auctions for resources with planning periods of less than 4.5 years and 4 years respectively. In these auctions, the reserve price used in each case was two times "the cost of new entry" (CONE), as established by CREG; a price floor of one-half CONE was also used, so the CREG was committed to purchase all energy offered at that price.

The second auctions ("the GPPS auctions") were for new generation projects with longer construction periods where the reserve price in each case was the "market-clearing" price established in the immediately preceding descending clock auction.

The auction rules, including some changes introduced in 2011, are described in detail in recent CREG documents and in Cramton and Stoft (2007) and Harbord and Pagnozzi (2008), and are not repeated in detail here. Rather, in Sections 2.1 and 2.2 we briefly summarize the outcomes of the two auctions, and consider various elements of the auction designs which may require further consideration or revision. Section 3 contains our proposals and recommendations.

2.1 The Descending Clock Auctions

The first descending clock auction occurred on 6 May 2008 and allocated OEFs for the period 1st December 2012 to 30th November 2013 for existing generating units (i.e. one year), and from 1st December 2012 to 30th November 2032 for three new power plants (i.e. twenty years). Ten new power plants were offered in the auction, by eight bidders, with a combined capacity of 9,185 GWh per year. One participant, Gecelca, offered three plants of 1117, 1117 and 745

GWh per year respectively. Table 6 summarizes the breakdown of new capacity offered in this auction.

TABLE 6: Plant Offered in the June 2008 DCA

Company	**Plant**	**Type**	**OEF Offer**
Isagen	Amoyá	Hydro	214
Gecelca	GE 2, 3, 7	Coal	2,979
Poliobras	Termocol	Fuel Oil	1,678
Cosenit	Termodial 1	Petroleum	208
Merilectrica-cc	Merilectrica-cc	CC-Gas	602
Proeléctrica	Termoandinai	Gas	766
Termocandelaria	Termocandelaria-cc	CC-Gas	1,449
Termotasajero	Tasajero 2	Coal	1,290

The auction "clock" started at a reserve price of \$26.09/MWh (2xCONE) reducing to \$22/MWh in the first round, and then decreased in \$2/MWh decrements in each subsequent round. The first capacity withdrawals occurred in Round 3: Gecelca withdrew one of its larger plants (1117 GWh) at \$20/MWh, the round opening price; Cosenit withdrew its 208 GWh plant at \$19/MWh; and Termocandelaria withdrew its 1449 GWh plant at \$18.025. There was one further capacity withdrawal in Round 4 (Merilectrica - 602 GWh), and two in Round 5 (Proelectrica – 766 GWh; Termotasajero - 1290GWh). Round 5 ended with an excess supply of 907 GWh at a price of \$14.00/MWh.

By the beginning of Round 6 two bidders had become pivotal: Gecelca with plants of 1117 and 745 GWh respectively, and Polibras with a single plant of 1678 GWh. Poliobras did not respond to this opportunity to exercise its market power and continued to bid in its unit at the round closing price of \$12/MWh. Gecelca, on the other hand, withdrew its smaller plant at a price of \$13.999 and its larger plant at a price of \$13.998/MWh. This resulted in the auction ending at a closing price of \$13.998 (with an excess supply of 163 GWh), and Gecelca's larger plant was allocated an OEF at this price. It thus appeared that Gecelca saw an opportunity to end the auction at a favorable price and took it. Perhaps it was not surprising that the one example of strategic supply reduction observed in the auction came from the only bidder with a large stake in both existing plant and in new resources.[8]

In light of this experience, in our previous report (Harbord and Pagnozzi 2008) we recommended that:

1. More consideration be given to the types of common value uncertainty faced by bidders in the auctions, and whether holding a descending-clock auction (DCA) is justified. The

[8] Gecelca also sold OEFs on 9,414 GWh of existing capacity at this auction closing price.

main purpose of a descending-clock auction is “price discovery”, i.e. to allow agents to revise their reserve prices in light of the information revealed by the bidding behavior of other agents during the auction. However, all of the auction participants we spoke with reported that their reserve prices did not (and would not) change during the auction. This may be due to the particular types of uncertainty faced by the bidders. Given this, different auction formats, such as sealed-bid auctions, should be considered.

2. The combination of indivisible or "lumpy" capacity bids with the auction information rules (i.e. revealing excess supply to bidders during each round of the auction) made it more likely that when one or more large bidders become pivotal, they would end the auction at prices exceeding the competitive market-clearing level. The indivisibility of offers reduces the cost of withdrawing supply in order to obtain a higher price. A re-evaluation of the auction information rules was therefore recommended if further descending-clock auctions were to be held.

The information transmitted to bidders before and during the May 2008 auction was:

- the demand curve to be used by CREG in the auction and the value of CONE ($13.045/MWh);
- the aggregate capacity/energy offered at the reserve price in advance of the auction and technical parameters for new and existing power plants; and
- each round’s opening and closing price and the aggregate excess supply at the closing price at the end of each round.

The supply bids of the individual bidders were not reported to avoid providing information which could be used to support tacit collusion.

Since the 2008 auction ended at the first point at which any active bidder became pivotal, and on the basis of bids which were evidently finely-tuned to achieve this outcome, in Harbord and Pagnozzi (2008) we suggested a reconsideration of the information reported to bidders during the auction in order to make it harder to manipulate the auction outcome. In particular, reporting aggregate excess supply, along with precise information about the auction demand curve allows bidders to see exactly when their capacity becomes pivotal, and thus to end the auction at prices which do not reflect actual energy costs. In Harbord and Pagnozzi (2008) we offered a number possible ways of dealing with this problem:

(i) making the auction a sealed-bid auction for all bidders, rather than just for bidders on existing resources;

(ii) not reporting any information on supply or excess supply during the descending clock auction;

(iii) reporting only total (rather than excess) supply during the auction, and not providing bidders with any information on the demand curve;

(iv) introducing a random component in demand, so that reported information on excess supply was sufficiently uncertain to make price manipulation strategies more risky for bidders; or

(v) allowing the auctioneer to reduce demand after observing the bids submitted in any round.

Each of these rules was designed to prevent bidders from manipulating the auction outcome by reducing their ability to identify the precise point at which their supply becomes pivotal.

Prior to the December 2011 clock auction, the CREG changed the auction rules by adopting recommendation (iv) above, and introducing a random component in the demand curve used to determine the auction allocation, and reported to bidders. Specifically, by defining a level of demand $\overline{D}$ using the formula,

$$\overline{D} = D[1 + vd \cdot va(-1, +1)], \tag{1}$$

where:

D = actual "objective" demand defined by the CREG for the year in question (in KWh);

$\overline{D}$ = demand to be used in the auction demand curve $p(q)$ reported to bidders[9];

vd = demand variation parameter to be chosen by the auctioneer with values in the range $[0, 0.015]$; and

va = uniformly distributed random component taking on values between -1 and 1.

The value $\overline{D}$ thus potentially varies between 1.5% and -1.5% of the actual value D, and this value was used in reporting auction demand to bidders.[10] In addition, at the beginning of each round of the December 2011 auction bidders were informed of the round's opening and closing price and the aggregate supply offered at the closing price of the preceding round (rather than the excess supply reported in the 2008 auction).

Table 7 shows the price and capacity offers of the 7 bidders in the December 2011 descending clock auction. The auction opening price was \$28/MWh and decreased to \$24/MWh in Round

[9] This demand curve can be found on p. 7 of CREG Resolución 139 of 06 October 2011.

[10] The auctioneer subsequently chose a demand variation parameter value of zero for the December 2011 clock auction. The bidders in the auction were not informed of this, however.

Table 7: Plant Offered in the December 2012 DCA

Planta	Clase de Planta	Número de la Ronda	Precio de Apertura USD/MWh	Precio de Cierra USD/MWh	Oferta USD/MWh	ENFICC (Gwh-año)	Capacidad MW	Resultado
Existentes	Existentes	3	22	12	12,0	60.333		Asignadas
AMBEIMA	Nuevas (N)	3	22	12	12,0	75	45	
Carlos Lleras Restrepo	Nuevas (N)	3	22	12	12,0	200	78	
SAN MIGUEL	Nuevas (N)	3	22	12	12,0	123		
Tasajero II	Nuevas (N)	3	22	12	15,4	1.165	140	
Tasajero II	Nuevas (N)	3	22	12	15,4	42	5	
Tasajero II	Nuevas (N)	3	22	12	15,4	42	5	
Tasajero II	Nuevas (N)	3	22	12	15,4	42	5	
Tasajero II	Nuevas (N)	3	22	12	15,4	42	5	
GECELCA32	Nuevas (N)	3	22	12	15,7	1.971	250	
TERMOBOLIVAR	Nuevas (N)	3	22	12	17,2	1.656	210	NO Asignadas
TERMOANDINAI	Nuevas (N)	3	22	12	21,9	808	100	
GECELCA31	Nuevas (N)	2	24	22	23,0	1.380	175	
Tasajero II	Nuevas (N)	1	28	24	28,0	42	5	
Tasajero II	Nuevas (N)	1	28	24	28,0	42	5	
Tasajero II	Nuevas (N)	1	28	24	28,0	42	5	

1, \$22/MWh in Round 2, and \$12/MWh in Round 3. In Round 1 Tasajero withdrew three small coal plants at the auction opening price, and in Round 2 Gecelca withdrew its 175 MW coal plant at a price of \$23/MWh.

Before Round 3 began, the auctioneers became concerned that another significant capacity withdrawal would result in a situation where the remaining large bidders would know, with reasonable certainty, that if either of them stopped bidding immediately near the highest price of the round, they could bring the auction to an end and sell their remaining capacity at that price. For example, if the rounds had proceeded with \$2/MWh decrements as initially planned, and Celsia (Colinversiones) had withdrawn its 200 MW coal plant at a price above \$18/MWh say (rather than at \$17.2/MWh), excess supply at that point would have been approximately 1,331 GWh/año with a range of approximately [379 GWh/año, 2,284 GWh/año] because of the demand uncertainty parameter. Hence Gecelca could have seen that it was very likely that a withdrawal of its 250 MW coal plant would have closed the auction at \$18/MWh. For this reason the auctioneers decided at the end of Round 2 to effectively hold a sealed-bid auction in the range [\$22 MWh, \$12 MWh], and end the auction in a single further round.

The problem which confronted the auctioneers at the end of Round 2 was, of course, precisely the issue that arose in the May 2008 DCA which we addressed at some length in our 2008 report. As noted above, the CREG's solution was to introduce a random component in the demand curve to be used in the December 2011 auction, but this was evidently insufficient. The problem arose a second time because of the combination of indivisible capacity bids and a number of large bidders in the auction. At the end of Round 2, Gecelca's remaining offer constituted 32% of the remaining new supply; Colinversiones' offer 27% and Tasajero's offer 22%. Despite the element of uncertainty concerning actual demand, and hence the true value of excess supply, the auctioneers were probably correct to be concerned that any further large capacity withdrawals would result in the remaining large bidders acquiring significant market power via an ability to end the auction at a noncompetitive price.

2.2 The GPPS Auctions

The "GPPS" auctions are for generation projects with longer construction or planning periods, and allocate OEFs for periods of up to twenty years to cover incremental demand over five or six year periods. The reserve price in these auctions is the "market-clearing" price established in the preceding descending clock auction. In the first GPPS auction held in June 2008, if insufficient supply was offered to cover incremental demand, then the reserve price was to be paid; if supply exceeded demand in any year, a sealed-bid auction was to be held.

The first GPPS auction used a reserve price equal to the closing price of the May 2008 descending clock auction of $13.998/MWh. Total demand was 6,285 GWh, being the sum of the incremental demands specified for each year. Bidders were required to first submit their quantity offers for each of the five years covered by the auction. They were only required to submit price offers in a sealed-bid auction if supply exceeded demand in any of the five years.

Since the incremental supply offered by bidders was less than incremental demand in every year, the reserve price was paid to the six bidders for power plant projects commencing from December 2014 to December 2018 As observed in our previous report (see Harbord and Pagnozzi 2008, pp. 12-13), it appeared that the auction participants were able to split their offers over five years in a manner which allowed them to implicitly "coordinate" on a "high-price" equilibrium in which all offers were accepted at the reserve price. This made the protection of the reserve price crucial. However, the auction nevertheless resulted in *de facto* excess supply in the first two years, since the total available supply of firm energy from 2014-2016 exceeds aggregate demand in those years.

For the second GPPS auction of January 2012, the CREG adopted our recommendation (see Harbord and Pagnozzi 2008, pp. 27-28) that bidders should submit their quantity and price offers at the same time, rather than making a sealed-bid auction dependent on excess supply. This was to make it harder for bidders to coordinate on low quantity offers in each year, since it provides incentives for each bidder to try to be awarded a larger quantity at a price just below the reserve price.[11] Table 8 summarizes the offers and results of the January 2012 GPPS auction.

Table 8: GPPS Auction Results January 2012 (Gwh/año)

Company	Project	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	Asignado 2008	Todo Asignado	ENFICC
ISAGEN	Sogamoso	1.440						2.350	3.791	3.791
EPM	Pescadero Ituango						3.482	1.085	4.567	8.563
TERMONORTE	Termonorte		619						619	619
PRODUCCIÓN DE ENERGÍA	Porvenir II			1.445					1.445	1.445
ISAGEN	Cañafisto						500			
Incremento Oferta		1.440	619	1.445	0	0	3.982			
Incremento Demanda		3.490	3.687	3.926	4.139	4.768	4.353			
80% Incremento Demanda		2.792	2.950	3.141	3.311	3.815	3.482			
50% Incremento Demanda		1.745	1.844	1.963	2.069	2.384	2.177			
Asignados		1.440	619	1.445			3.482			
Precios Asignados ($ US/MWh)		15,7	14,9	11,7			15,7			

Because the first two offers came from plant which had been assigned OEFs in the 2008 GPPS auction (Sogamoso and Pescadero Ituango), they were given priority over any competing offers and both (rationally) bid the reserve price of \$15.7/MWh. Thus, although Cañafisto offered a price of \$15/MWh for 2021-22, Pescadero Ituango's offer was taken first and exhausted available demand in that year at a price of \$15.7/MWh. Existing plant was able to bid for up to 80% of the demand increment in any year, while new plant could bid for up to 50%. Demand increments for each year were published and known to bidders prior to the auction. Bids were allowed to be divisible: for example Termonorte offered a minimum quantity of 124 GWh/año,

[11] We also suggested that: (i) the CREG could provide less information on annual incremental demand, for example by providing information on the total five-year demand only; and (ii) bidders should be required to offer in a single year the entire quantity they wish to offer in the auction from any new plant or project, preventing the spreading of offers over multiple years.

and Porvenir and Cañafisto offered minimum quantities of 0 GWh/año.

Since,as it turned out, only one offer was accepted in any year, each offer received its bid price. Had there been two or more offers accepted in a given year, each would have received the highest accepted offer for that year, i.e. the market-clearing price.

3 Issues and Proposals

The 2008 descending clock auction ended at the first point at which any active bidder became pivotal, and on the basis of bids which seemed to be fine-tuned to achieve this outcome. Despite the introduction of an element of demand uncertainty by the CREG, the 2011 descending clock auction was effectively aborted after two rounds by the auctioneers due to concerns that this was likely to happen again. The combination of indivisible supply bids and the offers of large generation projects relative to demand means that this issue will in all probability continue to arise in subsequent auctions.

Given this experience, we consider three possible options for addressing this problem in the shorter-planning period (DCA) auctions:

1. an increase in the amount of demand uncertainty factor, to say 4%-5%;
2. the use of a combinatorial clock auction with a subsequent sealed-bid stage, as suggested in the auctioneers' report; or
3. adoption of a sealed-bid uniform-price or discriminatory-price auction

We also consider a number of other issues associated with the indivisibility of bids in previous clock auctions, demand estimation and the planning period, and the rules relating to price formation and the treatment of existing plant in the GPPS auctions.

3.1 Increased Demand Uncertainty

A potential variation in total demand of 1.5% may appear to be small. It is important to recall, however, that what matters from the point of view of bidders is demand net of existing firm energy supply. Since existing supply accounted for more that 90% of the descending clock auction demand, the variation in net demand introduced by an uncertainty factor of 1.5% is already large.[12] Bidders unable to obtain reasonably accurate estimates of net demand lack the information needed to decide on the generation projects which it makes sense to offer, and this places a limit on the amount of demand uncertainty which it makes sense to introduce. In addition, demand variation much above 1.5% creates the risk that the range of demand uncertainty

[12] That is, a variation in total demand of 1.5% results in a variation of net demand by approximately 50%.

will include the level of demand of previous years. Hence it is probably not feasible to address the problem of pivotal bidders by further increases in the demand uncertainty parameters.

3.2 Combinatorial Clock Auction (CCA)

A CCA (as used in spectrum auctions in a number of European countries) is an appropriate design for auctions in which bidders have different (heterogeneous, but similar) objects to sell and there are complementarities between them, because it allows bidders to bid on packages of objects thus avoiding the exposure problem. The Colombian firm energy auctions are for a single (potentially divisible) product - firm energy in GWh. In this case there is usually no need for a combinatorial auction.

A combinatorial auction may be useful when bidders have decreasing marginal costs of production from a single plant, so that a bidder may be willing to sell a larger quantity at a lower per unit price than a smaller quantity, from a given plant (which is basically a form of complementarity). But the use of a combinatorial auction introduces a number of additional complications. For example, a particular and typically complex pricing rule must be chosen, and Vickrey prices have usually been excluded (Cramton, 2012). The "second-price" rule adopted in a number of CCA spectrum auctions has some undesirable properties: (i) it may lead to different bidders being paid different prices for identical quantities of energy; and (ii) it makes it very difficult for bidders to anticipate how their bids will affect the final auction prices, which may make them unwilling to bid truthfully.

Moreover, an activity rule must be designed for the clock stage of the auction, and there is no agreement to date over the most appropriate one (Ausubel and Cramton, 2011). Hence, the additional cost in complexity created by a combinatorial auction, both in terms of implementation by the auctioneer and choice of bidding strategies by participants, likely outweighs any advantages in resolving issues to do with economies of scale (unless these issues become of first order importance for bidders).

3.3 Sealed-bid Uniform-Price or Discriminatory-Price Auction

Our recommendation is that any further firm energy procurement should be single-round, sealed bid auctions. In our conversations with auction participants in 2008 and 2012, all reported that their reserve prices did not (and would not) change during the auction. Given that "price discovery" does not play any significant role from the point of view of the bidders in these auctions, a sealed-bid format for further auctions appears to be the best solution.[13]

[13] It is notable that none of the bidders in the December 2012 auction complained about the fact that the auction was reduced to a sealed-bid auction after two rounds.

We consider two alternative sealed-bid procurement auctions formats for a homogeneous divisible good such as firm energy. In each case we consider auctions in which bidders submit sealed bids that represent their supply functions – i.e. the lowest prices at which they are willing to sell different quantities of firm energy, and their bids are indivisible.

3.3.1 Uniform-price vs. discriminatory-price auctions

The two most commonly used multi-object sealed-bid auctions are the uniform-price auction and the discriminatory-price auction. In both auction formats the quantity of energy that is acquired by the auctioneer is equal to the quantity that equates bidders' total supply to the auctioneer's demand. But while in a uniform-price auction all energy is sold by winning bidders at the same market-clearing price, in a discriminatory-price auction each winning bidder is paid its actual bid for the quantity that it sells – i.e. the price determined by its supply function.

Arguably, the main advantage of a uniform-price auction is that it satisfies the "law of one price": since all firm energy is sold at the same price, no bidder is paid more than the others for an identical good. This is usually a desirable characteristic since, for example, winning bidders who are paid lower prices are uncomfortable explaining (to superiors or shareholders) why others received more favorable prices, and may then be less willing to bid aggressively due to this price risk.

A potential disadvantage of uniform-price auctions, however, is that they may have multiple Nash equilibria, in some of which bidders implicitly coordinate on high prices (e.g. Wilson, 1979). These equilibria can appear collusive, although they may simply arise from implicit coordination, rather than explicit collusion, among bidders.[14] The auction theory literature has demonstrated the existence of these high-price equilibria under the assumptions that the quantity demanded by the auctioneer is fixed and bidders can submit continuous supply functions.[15] Alternative assumptions can affect this result. First, the auctioneer can reduce high-price equilibria in uniform-price auctions by demanding a random rather than fixed quantity (Klemperer and Meyer, 1989), or it can eliminate them altogether by maintaining the flexibility to adjust its demand after receiving bidders' bids (McAdams, 2007). Moreover, high-price equilibria do

[14] Basically, under some assumptions, bidders can implicitly agree to share among them the total quantity that the auctioneer is willing to purchase, by each bidding extremely aggressively for smaller quantities than its equilibrium share, thus deterring other bidders from winning larger quantities. In other words, by submitting very steep supply functions – that is, bidding very low prices for relatively small quantities and much higher prices for larger quantities – bidders may make it unprofitable for a competitor to try to win a larger quantity than its equilibrium share, since to do so it would have to substantially reduce the auction price (because of the very low prices bid for small quantities by other bidders). This strategy is commonly referred to as "demand reduction" (or "supply reduction" in procurement auctions) and it may result in the auctioneer paying much higher prices for energy than bidders' marginal costs.

[15] Under these assumptions, bidders can submit bids that prevent competitors from bidding aggressively by creating a trade-off between a small quantity increase and a large price reduction.

not arise if bids are discrete (as in almost all actual auctions) and the quantity demanded is random.[16] Finally, the existence of high-price equilibria also depend on the auction allocation rule: "pro rata at-the-margin" (where bids below the equilibrium price are given priority while bids at the equilibrium price are rationed proportionally) make high-price equilibria easier; "pro rata" (where all bids are rationed proportionally) make high-price equilibria harder (Kremer and Nyborg, 2004a).

Apart from the existence of high-price equilibria which result from coordination among bidders' strategies, uniform-price auctions also encourage unilateral supply reduction by individual bidders. Supply reduction is particularly likely when there is a large bidder that, by manipulating its supply, can unilaterally produce a substantial effect on the final auction price. This strategic behavior is akin to that of a monopolist, who prefers to sell a lower quantity charging a higher price – i.e. to reduce its supply of marginal units in order to increase the price of inframarginal units.

Although high-price equilibria resulting from unilateral, or implicitly coordinated, supply reductions may occur in *sealed-bid uniform-price auctions*, these equilibria are much less likely than in a dynamic auction such as a descending clock auction. The reason is that in an ascending auction, bidders can observe the total quantity bid by competitors, and how this quantity varies as the auction price decreases. This provides them with additional opportunities of signaling their strategic intentions (of, for example, terminating the auction sooner at higher prices). And perhaps more importantly, in a dynamic auction a large bidder can learn the exact price at which it can terminate the auction by reducing the quantity it supplies.

In discriminatory auctions coordinated supply reduction resulting in high-price equilibria is less of a problem because each bidder receives its actual bid for the quantity that it sells to the auctioneer. In this case, bidding aggressively for small quantities (which makes it unprofitable for a bidder to try to obtain a larger quantity than its 'collusive' share) is very costly, so bidders submit flatter supply functions that induce greater price competition (see for example, Back and Zender, 1993). Arguably, this is the main advantage of a discriminatory-price auction compared to a uniform-price auction.

Since winners receive their own bids in a discriminatory-price auction, they need to have good information about the distribution of their rivals' valuations in order to determine an optimal bidding strategy (see Persico, 2000). So bidding may be especially complex for small bidders. By contrast, in a uniform-price auction a small bidder can simply bid his own valuation (reserve price), and let the auction price be determined by its rivals' bid. So a discriminatory-

[16] The intuition is that, with discrete bids, a small price reduction can result in a large increase in quantity and, with non-fixed demand, competition for marginal units reduces the auction price, and so the highest possible equilibrium price ratchets down (Kremer and Nyborg, 2004b).

price auction may discourage the participation of small bidders who have only small amounts of energy to sell and for whom the cost of obtaining detailed market information may not be worth paying.

The academic literature on discriminatory-price and uniform-price auctions finds neither auction format for sealed-bid multi-object auctions to be unambiguously superior to the other (see, for example, Fabra, von der Fehr and Harbord, 2006). The empirical evidence is also inconclusive.

Since the CREG's firm energy auctions set firm energy prices both for actively bidding new supply and for existing plant covered by OEFs, there is a clear argument for using a uniform-price auction to set the market-clearing price.[17] The uncertainty about competitors' strategies and the actual market-clearing price generated by a sealed-bid auction will likely be sufficient to discourage bidders from strategically reducing supply to increase the auction price. Hence, the advantages of a uniform-price auction in terms of price uniqueness and simplicity for small bidders make it a preferable choice over a discriminatory-price auction.

3.3.2 Choice of price in a uniform-price auction

For technological reasons (related to productions costs), the Colombian auctions for firm energy treat the supply bids for firm energy as indivisible: either the bidders sells the quantity bid, or none of it. A consequence of this is that bidders' supply functions are discrete "step functions" and small changes in the auction price can induce large variations in the quantity supplied.

With discrete supply functions, there is some flexibility in the definition of a market-clearing price: any price between the highest winning (or accepted) bid and the lowest losing (or rejected) bid can equate demand and supply.[18] Moreover, because of the indivisibility of bids these auctions will generically terminate with either excess supply or excess demand.

The CREG´s descending-clock auctions have been designed to result in excess supply (because all firm energy demand has to be satisfied) at an auction price equal to the highest accepted bid. But in a sealed-bid auction, this may increase bidders' incentive to strategically reduce supply. The reason is that the incentive to unilaterally reduce supply stems from the fact that, if a bid is pivotal, it affects the price paid to all winners. So bidders have an incentive to increase their bids, even though this may reduce the quantity they sell. But with indivisible bids, the marginal winning bid can be increased without affecting the quantity sold by the marginal winning plant (except in the unlikely event of a tie). In other words, when the auction price is equal to the highest accepted bid, by strategically increasing its winning bid for a plant a bidder

[17] This market-clearing price also serves as the reserve price used in the GPPS auctions.

[18] In the auction theory literature, the price of a uniform-price auction is typically defined as the lowest rejected bid - e.g. Milgrom, 2004.

can increase the price paid for the energy produced by that plant (as well as any other winning plant) without affecting the quantity of energy that it sells.

By contrast, if the auction price is equal to the lowest rejected bid, increasing a bid will increase the auction price only if this bid is rejected. Hence, a bidder may increase the price it is paid for its other winning plants only by increasing its bid for a losing plant; *but a bid for a specific plant or unit will never affect the price paid for the energy produced by that plant.* Therefore, we would expect bidders to perceive a lower incentive to reduce supply in a uniform-price auction when the auction price is equal to the lowest rejected bid (since by reducing supply a bidder may end up only increasing the price paid to the other winning bidders, when it is not a winner). For example, if a bidder offers a single plant, it has no incentive to reduce supply when the auction price is equal to the lowest rejected bid (since if its bid determines the auction price it will not sell any energy), while it does have an incentive to reduce supply when the auction price is equal to the highest accepted bid.

Choosing a market-clearing price equal to the lowest rejected bid may appear to be the preferable option. However notice that, for any given set of bids, an auction price equal to the lowest rejected bid (rather than the highest accepted bid) increases the price paid by the auctioneer for all the firm energy that it purchases, and nothing guarantees that this price differential will be small. In our view, both options should be given further consideration. The "least change" option is to continue with current rule of setting the market-clearing price equal to the highest accepted bid.[19]

3.4 Other Issues

3.4.1 Divisible bids

Because of the "lumpiness" or indivisibility of capacity bids in the firm energy auctions, the CREG is forced to accept marginal (i.e. price-setting) bids which can result in excess supply at the auction closing price. The excess supply contracted in the May 2008 DCA was 163 GWh/año (about 5.42% of the amount purchased), and in the December 2011 DCA it was also small.[20]

A possible, partial solution to this is to use a combinatorial optimization process to determine the least-cost combinations of bids which satisfy demand, rather than automatically assigning OEFs to the lowest bidders. Given the small margins of excess supply contracted in previous auctions, this may make little or no difference to the final allocation. Nevertheless, it would likely entail adopting a new pricing rule (such as pay as bid), and as noted above, this entails a

[19] We might have also considered multi-unit Vickrey auctions for firm energy, but these are significantly more complex, do not result in a uniform price, and face well-known difficulties (see Fabra, von der Fehr and Harbord 2002, Section IV and Milgrom 2004, Ch. 2 for discussions).

[20] This issue does not arise in this form in the GPPS auctions, as the CREG never accepts bids which result in excess supply in those auctions.

new approach to remunerating existing plant and setting reserve prices for the GPPS auctions.

Another partial solution is to allow the CREG discretion to end the auction with excess demand, particularly when covering demand would involve contracting substantial amounts of excess capacity.

As noted, the amounts of excess supply contracted in past clock auctions has been small, although this does not guarantee that will always be case under the current rules. We view this an issue which the CREG may wish consider, but at present it is not a priority.[21]

3.4.2 Planning period and demand issues

Planning period A number of the auction participants suggested that the planning period for the descending clock auctions of 4.5. and 4 years respectively has been too short. As evidence for this it was pointed out that none of the new generation plant assigned OEFs in the May 2008 clock auction will be in operation by December 2012, as initially planned. Planning periods of 5 years or greater have therefore been proposed. If this recommendation is adopted the opportunities for combining the clock and GPPS into a single auction are increased. Harbord and Pagnozzi (2008) contained some proposals for doing this.

Demand issues It has also been suggested that the CREG does not properly take account of all existing capacity, particularly that placed in earlier GPPS auctions, when estimating firm energy demand for subsequent auctions. For example, the second descending clock auction of December 2011 was to cover demand for the period December 2015 - December 2016, and net demand for that year less than 4,000 GWh (i.e. objective demand less existing firm energy contracted). The CREG contracted for an additional 3,700 GWh/año of new firm energy capacity in this auction. However, Isagen's Sogamoso plant which was selected in the 2008 GPPS auction will begin operation in December 2014, and with spare (i.e. uncontracted for) firm energy capacity in 2015-2016 of 2,991 GWh/año.[22] Similarly, Emgesa´s El Quimbo plant will have uncontracted firm energy capacity of 900 GWh/año in 2015-16. Together these add up to more than the net demand covered by the December 2011 auction.

Some suggestions for addressing this issue are:

(i) allow uncontracted ENFICC capacity from prior GPPS auctions to compete with new plant in the descending clock auctions

[21] An off-setting factor is that some of the new plant contracted for in past auctions has suffered significant construction delays, and in some cases construction has been cancelled altogether. Hence the apparent excess supply does not always materialize.

[22] Sogamoso's ENFICC less firm energy contracted for in that year.

(ii) treat uncontracted ENFICC capacity from prior GPPS auctions analogously with existing capacity in the descending clock auctions

(iii) subtract uncontracted ENFICC capacity from prior GPPS auctions from demand before the auction (i.e. in calculating Demanda Objetivo con Descuentos)

The problem with adopting either (i) or (ii) is that might provide increased incentives for withholding capacity from future GPPS auctions, although this concern is diminished if longer planning periods are introduced.

3.4.3 GPPS auctions

In the GPPS auctions there are two types of plant (or bidders). Plant which has been allocated OEFs in a prior GPPS auction, and new plant. Existing plant is given priority in filling the demand increment in any year, and are always able to obtain the auction reserve price. New plant must compete for an OEF allocation. There are a number of ways this system might be improved:

(i) if existing plant from previous GPPS auctions is to be given priority, it should not set the market-clearing price in any year. The market-clearing price should be set by the highest accepted (lowest rejected) bid of new plant, when there are any

(ii) analogous to existing plant in the descending clock auctions, priority plant in GPPS auctions could receive the market-clearing price set by new plant, when there are any, and the auction reserve price otherwise

(iii) alternatively, if priority plant does not wish to passively receive the market-clearing price set by new plant in GPPS auctions, it may bid actively in the auction, but at the cost of losing priority and having its bids treated symmetrically with those of new plant

In order for these suggestions to be implemented it is recommended that the CREG consider changing the pricing rule in the GPPS by using the lowest rejected bid to set the market-clearing price in any year. When there are no rejected bids, the lowest rejected bid is set equal to the highest accepted bid.

4 Conclusions and Recommendations

1. Replace the DCAs with sealed-bid, uniform-price auctions using either the highest accepted or lowest rejected bid to set the market-clearing price.

2. Change the pricing rules in the GPPS auctions so that priority plant does not set the market-clearing price. Consider adopting a lowest rejected bid pricing rule.

3. Consider how best to take account of uncontracted capacity from prior GPPS auctions in determining future firm energy requirements.

4. Consider whether the planning period for the DCA auctions has been too short, and if increased, whether the DCA and GPPS auctions could be unified in a singe auction.

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