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Assessment of generators strategic behavior in long term supply contract auctions using portfolio concepts

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Abstract— **Long term supply contracts (LTSC) auctions are being used worldwide as a tool to stimulate system expansion in electrical markets. The need to assess the strategic behavior of generation investors is herein addressed. The assumption made is that risk aversion considerations directly affect Genco's strategic behavior, and an ad-hoc static competitive game model is constructed to prove this assumption, using portfolio concepts.**

The model is applied to the Chilean electricity market, using real parameters and the observed behaviors in the past October 2006 Disco's LTSCs auctions. Given that the Chilean LTSCs are auctioned using combinatorial auctions, simplifications are made to address the exponentially increasing simulating time cost in obtaining Gencos strategic behavior. For that purpose, a discrete number of possible prices to offer and reduced supply block division possibilities are used. The results obtained show that risk aversion concepts directly affect the auction results. Additionally, it is shown that only the spot price uncertainty can be hedged with LTSC and therefore it is the only relevant uncertainty in this. Both aforementioned conclusions must be taken into account in any LTSC auction design.

Index Terms— **Supply Contract Assessment, Portfolio Management, Combinatorial Auctions, Game Theory, Strategic Auction Behavior**

I. Introduction

A large volume of transactions are now a day being conducted through auctions. Examples range from the sale of treasury bills and foreign currencies, to oil fields and electricity contracts [1]. Auctions are being used worldwide to obtain not only better prices for an object or procurement contract sold, but to obtain an optimal allocation of them. Very intuitive examples where not only price but an optimal allocation is needed are the radio spectrum licenses auctions that were conducted by the United States, and the world famous draw-back case of New Zealand [2].

In the case of electricity markets both objectives must by addressed. From the point of view of the regulator, auctions must be capable of obtaining better prices for the supplied energy, and must provide a reasonable contract allocation output. A reasonable allocation output can be understood as one in which the bidders that get awarded an auctioned object are the ones that value it the most [3].

To obtain the above objectives a thoughtful and informed auction must be designed. The first step to address this is to produce a realistic modeling of the strategic behavior of the bidders. Through out the history of auction design research, different bidder's models have been proposed. Initially, symmetrical and risk-neutral bidders, managing independent information and private valuations of the auctioned objects were modeled [4]. In [5] a progress was made by modeling bidders as if their valuation were drawn from a common probability function, which has proved to be quite effective in some cases. Another advance was made by Wilson [6] introducing the pure common-value model, in which the individual valuation of the auctioned object absolutely depends on the valuation of the other bidders. To the end of the 1970's most of the basis of auction theory was set.

Although several papers achieved to relax the first modeling constrains (symmetrical bidders, independent information, and private valuation) it was not until the 1990's that major advances were obtained through the recognition of the marginal revenue concept involved in auction's allocations [7] and the recognition of risk aversion in bidders and auctioneers [8]. Both of the later are considered through out this paper.

Once an adequate model of the bidders has been achieved, the next step is to prove different auction models that can suit the auctioneer's preference. The most commonly used formats are the ascending, descending, first price sealed bid, Vickrey's, and different versions of Combinatorial Auctions. Due to the fact that none of the above can capture every desirable aspect of a given auction, a tailor made design based on some of this five formats, can better elicit the expected results.

As it has been repeatedly reported in the technical literature, combinatorial auctions achieve remarkably better results than single object auctions when bidders experiment substitubility or complementarities between the auctioned objects [9], [10]. The fact is that in electricity markets, substitubility is observed. This fact makes combinatorial auctions a good alternative of auction design.

In the case of electricity markets, much research has been done on auction design mainly concerning day-ahead markets [11], [12] and [13], but not much in LTSC. This might be explained in the fact that LTSC auctions for electricity markets have not been widely used. Examples of countries that actually are developing LTSC auctions with similar yet different approaches are Brazil and Chile. Both in Brazil and specially Chile, some combinatoriality over the auctioned contracts is permitted.

The fundamental difference between the day-ahead auctions

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and LTSC auctions is that the former only plays a short term role and is mostly related to the spot sells of Genco's energy. On the other hand long term supply contract auctions are intimately related to hedging considerations and therefore play a major role in system expansion and Genco's strategic behavior [14]. An approach to the modeling of the later can be found in [15]. Although [15] gives and enlightening first approach to long term supply contract auctions, the analysis fails to rescue two fundamental aspects: the convenience of combinatoriality and bidders risk-adverse behavior.

This paper makes use of basic financial tools through portfolio management and uses them to asses Genco's valuation of the contracts auctioned. Indeed, portfolio considerations largely explain Genco's risk-aversion. Herein, a combinatorial LTSC auction is modeled through a static competitive game. Information is assumed to be public and common, while valuations are privately assessed. To the best of our knowledge, studies addressing combinatoriality and risk aversion in LTSC auctions are scarce.

This paper is organized as follows. Section II models Genco's strategic behavior using easily supportable assumptions. Subsequently, section III frames the simplified strategic scenario in which the modeled Genco's will compete. Section IV applies the model to the case of the Chilean LTSC auctions, providing results in section V. Finally section VI summarizes the main conclusions.

II. THE MODEL: GENCOS BEHAVIOR AND ASUMPTIONS

The basic assumption is that Gencos can reasonably predict their annually expected generation over periods ranging from 8 to 12 years (these are common maturities of LTSC). Later in the paper, this is shown to be the case in the application to a real market.

The second assumption is that Gencos invest basically in two markets: the spot market and the contracts market (Fig. 1).

A third assumption is that Gencos can be modeled by just three fundamental parameters: (a) variable costs of generation in USD/MWh, (b) risk preferences, and (c) annually expected energy generation. These three fundamental parameters are the basis to asses a Genco's portfolio valuation, and correspondingly to asses its final payoff in a specific strategic equilibrium. This type of modeling better suits markets in which generation is centrally dispatched.

The Genco's benefit function to asses a given energy investment portfolio, is assumed to be similar to that proposed by Chavas and Pope [16]:

$$\tilde{\pi} = \tilde{p} \cdot [\tilde{y} - h] + b \cdot h - \tilde{r} \cdot \tilde{y} - c(h) \qquad (1)$$

Where $\tilde{p}$ is the average spot market price in USD/MWh over the life of the contract, $\tilde{y}$ is the amount of energy generated over the same period, and h is the amount of energy destined to the contracts market. Additionally, b represents the average contract price in USD/MWh, $\tilde{r}$ is the average primary energy cost in USD/MWh and $c(h)$ is the cost derived from hedging.

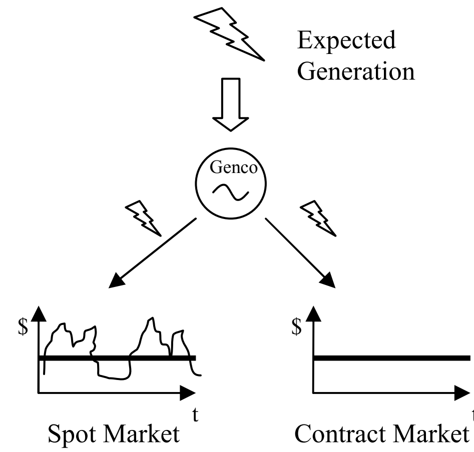

Fig. 1: Gencos portfolio conformation

Noting that the cost of hedging is insignificant compared to the flux derived from either the spot or the contract markets, equation (1) can be simplified to:

$$\tilde{\pi} = (\tilde{p} - \tilde{r}) \cdot \tilde{y} + (b - \tilde{p}) \cdot h \qquad (2)$$

In which $\tilde{y} = f \cdot \tilde{\varepsilon}$, where $\tilde{\varepsilon}$ is a random variable[2] that takes into account the difference between the projected Genco's generation "f" and the effective generation "$\tilde{y}$".

In the later equation, $\tilde{p}$, $\tilde{y}$ and $\tilde{r}$ are assumed to be stochastic, while b is supposed to be deterministic. The contracts price b is clearly deterministic because it represents the fixed price offered by Gencos for a supply contract in the contracts auction market.

An additional assumption is that Gencos have risk preferences represented by the following utility function, called **linear mean variance utility function**:

$$U[\tilde{\pi}] = E[\tilde{\pi}] - \gamma \cdot Var[\tilde{\pi}] \qquad (3)$$

In which:

$$\begin{aligned} &E[\tilde{\pi}] = (\bar{p} - \bar{r}) \cdot f + (b - \bar{p}) \cdot h \\ &Var[\tilde{\pi}] = \sigma_e{}^2 \cdot (\bar{p} - \bar{r})^2 + \sigma_p{}^2 \cdot (f - h)^2 + \sigma_r{}^2 f^2 \\ &+ \sigma_y{}^2 \cdot (\sigma_p{}^2 + \sigma_r{}^2) \end{aligned} \qquad (4)$$

(For the complete derivation of the later, please refer to appendix A)

Where σ_p is $\tilde{p}$'s standard deviation, σ_e is $\tilde{y}$'s standard deviation, and σ_r is $\tilde{r}$'s standard deviation.

Finally, it will be assumed that every possible outcome derived from Genco's strategic behavior during the auctions, will be assessed by each firm through equation (3).

It is important to notice the different sort of uncertainties that compose the risk scenario of a given Genco. The risks derived form the uncertainties of the effective individual energy generation σ_e and the primary energy cost σ_r are not

[2] With unitary expected value and standard deviation σ_e

hedgeable, at least in the contracts markets. Only the risk produced by the uncertainty in the spot market can be hedged. Indeed, one can think of the dispatch and cost risks as systematic risks, and the spot price risk as a diversifiable risk.

As expected, the optimal portfolio conformation is independent of the dispatch and costs uncertainties, and only depends on the risk aversion, the uncertainty of the spot price, and the expected spread between the spot and contracts prices.

$$optimal\ portfolio \Rightarrow \frac{\overline{p}-b}{2\cdot\gamma\cdot\sigma^2{}_p} = f - h \qquad (5)$$

III. The model: Strategic scenario

The strategic scenario is the following. It will be assumed that an energy block of a fixed GWh/year compromise is auctioned allowing combinatorial bids of 1/3 of the auctioned block.

Three Gencos participate in the auction which will be identified as G1, G2 and G3. Each Genco can place a bid corresponding to 50 USD/MWh, 55 USD/MWh or 60 USD/MWh for any number of combinations of the sub-blocks aforementioned. The auction follows a one shot sealed bid format.

The block divisibility was set to three and the possible prices to offer were also set to three (plus the alternative not to bid), mainly because of the simulating time stress the resolution of combinatorial auction produces[3]. Nevertheless, the significance of the derived results is guaranteed.

Taking into consideration all the possible strategies each Genco can use, including the possibility of not submitting a bid for one or all possible block combinations, the cardinality of the strategy space is $4\cdot4\cdot4=64$ strategies. The combination of these 64 individual strategies gives way to 262,144 possible equilibriums.

For each possible equilibrium, the optimal auction resolution must be obtained and the individual valuation of each Genco's portfolio derived must be calculated. With that information one is capable of building the strategic payoff matrix of the game and calculate the corresponding Nash equilibriums. To achieve the aforementioned result, a Matlab® program was developed. The flux diagram of the program is presented in Fig. 2 and the flux diagram of the awarding algorithm is presented en Fig. 3.

With the Nash Equilibriums obtained from the simulation, expected awarded contracts prices can be calculated. Additionally, Genco's strategic behavior over different risk preferences and strategic scenarios can be addressed.

IV. Application to the Chilean Electricity Market

As in many countries, the Chilean market makes a clear distinction between regulated and free consumers. A consumer is considered to be "free" if its average connected load exceeds 2 MW, obliging him to sign its own supply contracts with Gencos. If his average load lies between 0.5 and 2 MW the consumer is given the possibility to choose whether to be regulated or free. Consumers below 0.5 MW are obliged to maintain a regulated contract with the corresponding Disco who in turn signs long term supply contracts with Gencos at a regulated price (until law 20.018) called the **node price.**

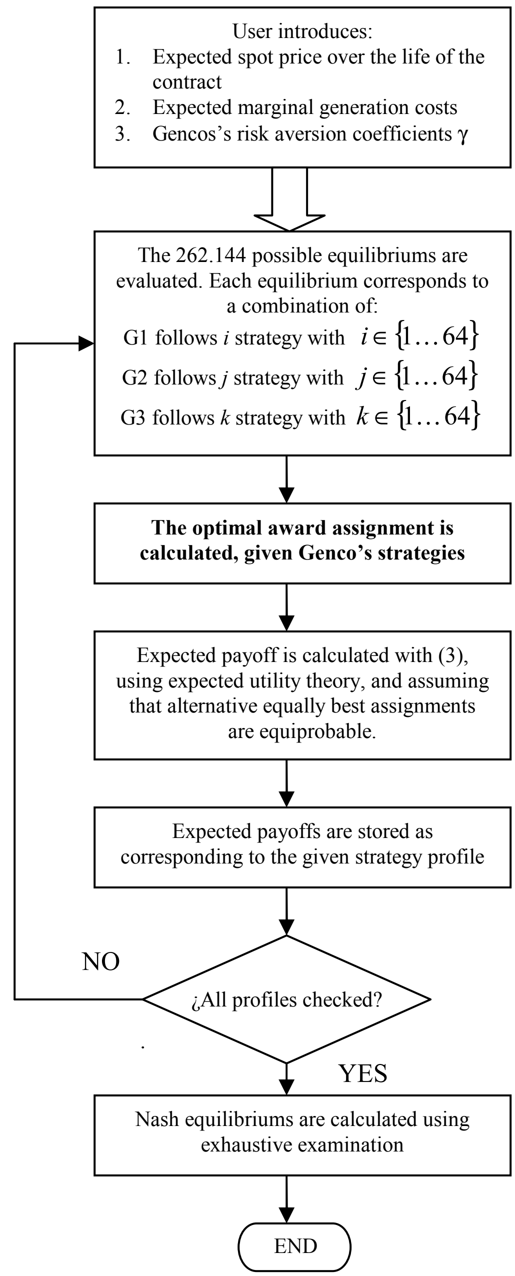

Fig. 2: Flux diagram of the Matlab® program

[3] Recall that the resolution of a combinatorial auction is an *np-complete* problem.

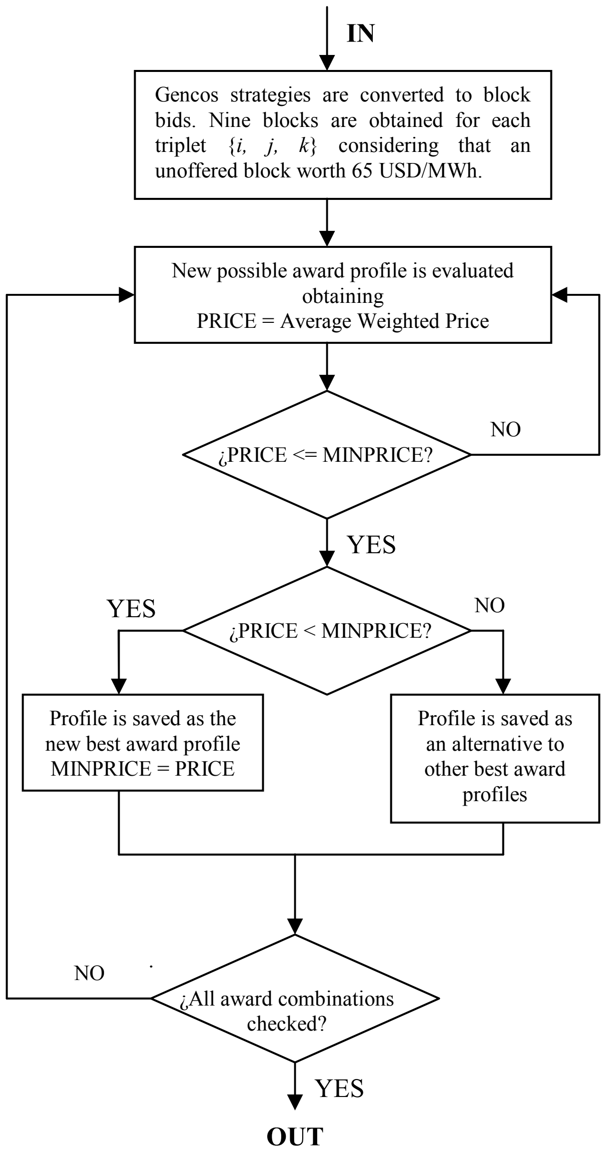

Fig. 3: Flux diagram of the awarding algorithm

In an attempt to deregulate this long term signing condition, an auction scheme was introduced through the promulgation of the so called Short Law II (law 20.018). The mentioned law established that every Disco must auction its energy supply requirements for regulated consumers, so to cover its needs for at least the three coming years. Additionally, it permitted Discos to agree auctioning their requirements jointly in groups. In the past October 2006 auctions, five Disco groups were voluntarily formed. Further, the bylaw that framed the law (Ex. Res. 704 CNE) introduced the "Jointly Awarding" method in which any participant Genco can offer bids to several different Discos or groups of Discos beyond its "declared capacity". The declared capacity is the maximum annual energy a Genco is willing to provide. Any given Gencos is awarded at most its declared capacity.

Following the mentioned framework, Discos were allowed to define their auction bases on their own. The scheme selected by Discos was the following. The auctions would be a "pay-as-bid" (charge-as-bid) sealed bid auction in which Gencos have permission to bid for combinable fragments of the total auctioned blocks (per Disco or group of Discos). The final allocation awards each block to one or several Gencos in order to obtain the least achievable average price for the MWh[4].

In the past October 2006 auctions, a total amount of 11,760 GWh/year was auctioned. Due to the so-called "Jointly Awarding" mechanism, it is logical to consider it as a big auctioned block which can be divided into sub-blocks that are combinable within the boundaries of each Disco or group of Discos.

Given the volume of the auctioned block, the possible prices to offer permitted by the model proposed in this paper, and the number of participant Gencos[5], the only parameter left to feed the model are the generating costs, the expected annual generation, and the "risk perceptions"[6].

The initial assumption that Gencos can reasonably predict their annually expected generation over long periods holds in this market. Figs. 4 to 6 show the annual evolution of the generated energy for the main three Chilean generating firms, over a 10 year period.

Both G2 and G3 follow a linear (at least in the period shown) and predictable annual generation. On the other hand, G1 seems to follow a periodical evolution of generated energy, which is in fact easily predictable due to the asset selling campaign G1 followed over the graphed period.

Given that the big three firms, controlling the 90% of the installed capacity in Chile, manage a diversified generating technology portfolio, an average variable cost was calculated per firm. The information to do so is publicly available, and biannually published by the CDEC [18]. The calculated average costs are shown in table 1 (firms identity has been reserved).

Table 1: Generating Cost per Firm

	G1	G2	G3
Generating Costs [USD/MWh]	17.12	13.38	10.82

In this same line, the expected annual generation per firm, intimately related to the firm's expansion policy, can be easily calculated using the known growth rate of installed capacity per firm in the past 12 years (Figs. 4 to 6), added to the readily recognizable market share strategies.

Finally, even though not strictly necessary given that the objective of the model is some what illustrative more than predictive, the risk perception of the firms was calculated using equation (5). The usefulness of this is to set a standard of what levels of risk aversion are reasonable to expect from generating firms. First of all, the amount of energy intended

[4] The Chilean awarding mechanism finally put in place does not achieve the minimum cost combination [15]

[5] In fact, in October 2006, only three firms and one colligated firm bided in the auctions.

[6] "Risk perception" will be understood as the product of the standard deviation of the spot price $\sigma_p{}^2$ times the risk aversion level γ.

for the spot market *f-h* (right hand side of the equation) can be easily calculated using information provided by the Chilean poolco CDEC. The energy generated and contracted per firm during the year 2006 is shown in table 3.

Table 2: Average Expected Annual generation over a 12 year period starting 2010

	G1	G2	G3
Average Expected Anual Generation over 12 year periods [GWh]	10,999	12,054	24,984

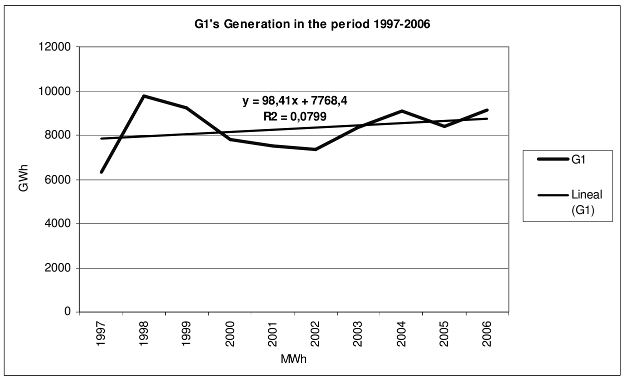

Fig. 4: G1's Generation over the period 1997 to 2006

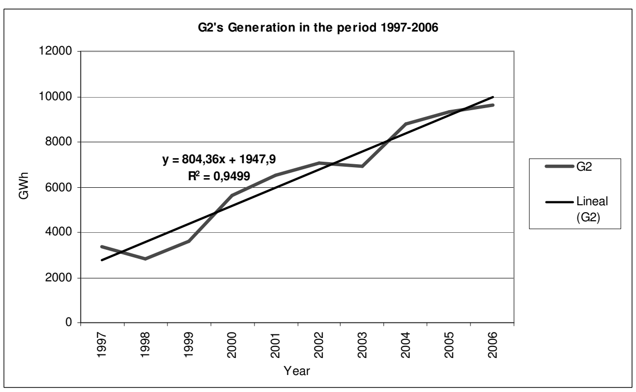

Fig. 5: G2's Generation over the period 1997 to 2006

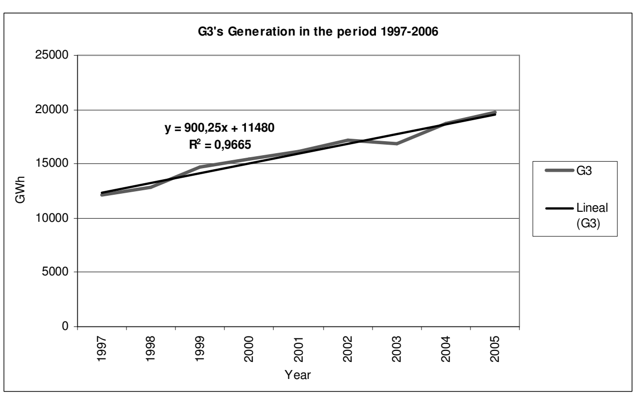

Fig. 6: G3's Generation over the period 1997 to 2006

Table 3: Energy Generated and Contracted per firm (2006)

	Generated Energy [GWh]	Contracted Energy [GWh]
Genco 1	9,144	11,309
Genco 2	9,651	11,560
Genco 3	19,762	14,814

The spread between the expected spot price and the contracts price $\overline{p}-b$ (left hand side of equation (5)) can be easily calculated using information available in [18]. Indeed the regulator publishes biannually a resume of the average spot price and the average contracts price per month.

Using the later information and the standard deviation of the spot price (calculated from the official prediction errors) typical parameters of risk aversion can be obtained. The results are shown in table 4.

Table 4: Risk Aversion Determination Using Real Markets Parameters

	G1	G2	G3
Average Contracting Level (2000-2006)	1.19	1.02	0.86
Average Contract Prices (2006) [USD/MWh]	51.995	51.995	51.995
Average Spot Price (2006) [USD/MWh]	45.758	45.758	45.758
Spot Price Standard Deviation [USD/MWh]	222.1	222.1	222.1
Risk Aversion	**0.57%**	**4.23%**	**-0.50%**

V. Results

With all of the above, a simulation of the Genco's strategic behavior was conducted, obtaining enlightening results. Although Gencos were obliged to declare maximum awardable capacities, that restriction was not imposed to the model mainly because in the modeled strategic scenario those restrictions should not affect the optimal strategic behavior. For convenience, the results are reported in two sections: results derived from the model, and results derived from the simulation.

A. Results derived from the model

The first result, derived from the model, deals with the ability of the LTSC to hedge the market's risks. As observed from equation (4), the only market risk that can be hedged with LTSCs is the spot price uncertainty. The uncertainties within the effective dispatch and primary energy cost are systematic to the contracts market and therefore do not influence Gencos strategic behavior.

The second result derived from the way Genco's portfolio valuation is modeled, is that the marginal utility produced by an additional signing level (contracting level of the Genco) is decreasing (Fig. 7). Therefore an optimal contracting level exists, and is given by equation (5).

Finally, it is easy to see that a combinatorial auction, permitting to submit bids for sub-block of the total auctioned energy, is going to be capable of obtaining results at least as good as those obtained from a rigid, full block award auction.

This is produced mainly because Gencos value more the first contracted MWh than the latest contracted.

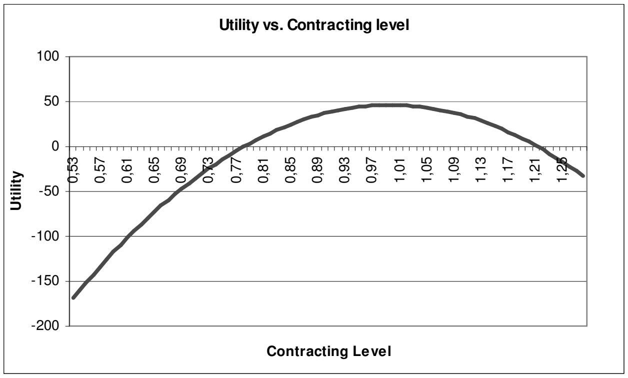

Fig. 7: Typical Genco's utility function vs. signing level, for Spot Price = 45,758 USD/MWh, Contract Price= 51,995 USD/MWh, $\gamma = 2\%$

B. Results derived from the simulation: The effect of risk aversion

The strategic scenario presented in III was simulated, using the Matlab® program. To simulate risk perception with similar values to that observed in practice, the model was calibrated using real operation data available for the year 2006.

Using the parameters of table 1, 2 and 4, results illustrated in Figs. 8 to 10 were obtained. These figures show how an increase in risk aversion, unilateral or simultaneous, improves the final overall performance (final average MWh price) of the auctions.

VI. CONCLUSIONS

As seen through out this paper, three mayor issues arise from the new long term supply contract auctions, being considered world wide, and its application in the Chilean regulated consumers market.

In the first place, one can conclude from equation (4) that the only hedgeable risk in this new contracts market is the spot price risk. Then a Genco's behavior in the auctions would be the same regardless of the dispatch and primary energy cost uncertainties, if not hedged. This means that only generating costs and risk aversion are relevant parameters in predicting Genco's strategic behavior, and not dispatch risk as previously supposed [20].

In the second place, due to the "portfolio like" assessment of the utility of a new energy contract with Discos, one concludes that the marginal utility of an additional contract is decreasing (if risk adverse). This means that a Genco, could eventually value more some sub-blocks of the total auctioned energy, or even a combination of them, instead of being obliged to acquire a whole block. Then, not only dividing an auctioned energy block is good through means of minimizing entrance barriers, but it is also good because it takes into account the substitubility Gencos see, making the whole process worthier for the auctioneer.

Finally, it was empirically shown that risk aversion dramatically influences Genco's strategic behavior (Figs. 8 to 10). The hope is that these conclusions will contribute to stress what is relevant and what is not to predict Genco's strategic behavior.

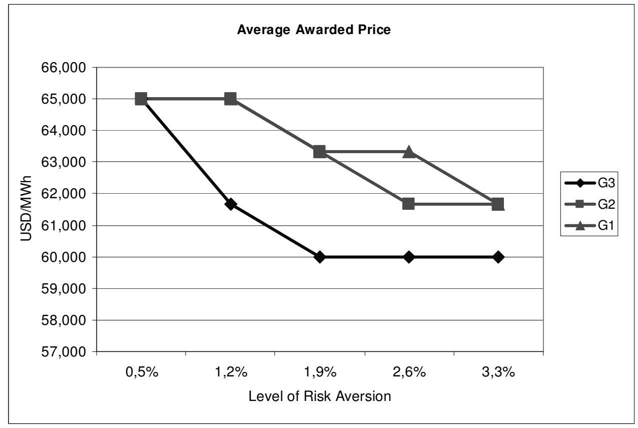

Fig. 8: Final auction price if two generators present low risk (0.5 %) aversion vs. third generators risk preference

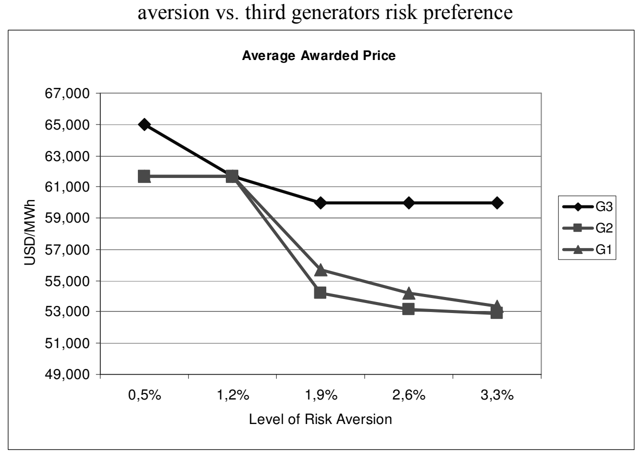

Fig. 9: Final auction price if two generators present medium (1.2 %) risk aversion vs. third generators risk preference

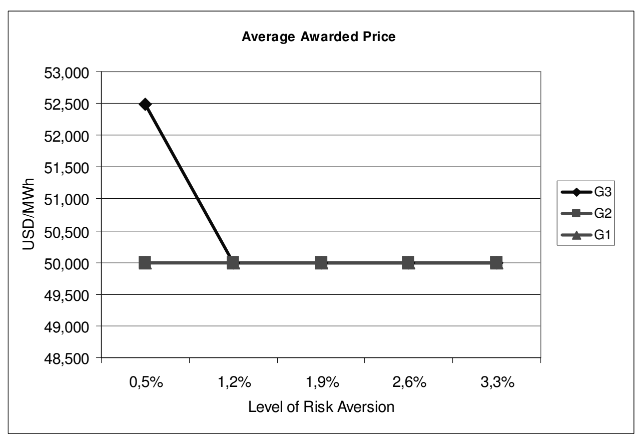

Fig. 10: Final auction price if two generators present high (3.3 %) risk aversion vs. third generators risk preference

VII. Appendix

A. Portfolio variance derivation

$$Var[\pi]=Var[(\tilde{p}-\tilde{r})\cdot\tilde{y}]+h^2\cdot Var[p]$$
$$-2\cdot h\cdot Cov[(\tilde{p}-\tilde{r})\cdot\tilde{y},\tilde{p}]$$
$$=\left\{E\left[(\tilde{p}-\tilde{r})^2\right]\cdot E[\tilde{y}^2]-E[p-r]^2\cdot E[\tilde{y}]^2\right\}+h^2\cdot Var[p]$$
$$-2\cdot h\cdot\left\{E\left[\left(\tilde{p}-\frac{\tilde{r}}{2}\right)^2\right]\cdot E[\tilde{y}]-E\left[\tilde{p}-\frac{\tilde{r}}{2}\right]^2\cdot E[\tilde{y}]-Var\left[\frac{\tilde{r}}{2}\right]\cdot E[\tilde{y}]\right\}$$
$$=\left\{Var[\tilde{p}-\tilde{r}]+E[\tilde{p}-\tilde{r}]^2\right\}\cdot\left\{Var[\tilde{y}]+E[\tilde{y}]^2\right\}$$
$$-E[\tilde{p}-\tilde{r}]^2\cdot E[\tilde{y}]^2+h^2\cdot Var[\tilde{p}]-2\cdot h\cdot\left\{Var\left[\tilde{p}-\frac{\tilde{r}}{2}\right]+E\left[\tilde{p}-\frac{\tilde{r}}{2}\right]^2\right\}$$
$$\cdot E[\tilde{y}]+2\cdot h\cdot E\left[\tilde{p}-\frac{\tilde{r}}{2}\right]^2\cdot E[\tilde{y}]+2\cdot h\cdot Var\left[\frac{\tilde{r}}{2}\right]\cdot E[\tilde{y}]$$
$$=Var[\tilde{y}]\cdot E[(\tilde{p}-\tilde{r})]^2+Var[\tilde{p}-\tilde{r}]\cdot E[\tilde{y}]^2-2\cdot h\cdot Var\left[\left(\tilde{p}-\frac{\tilde{r}}{2}\right)\right]\cdot E[\tilde{y}]$$
$$+h^2\cdot Var[\tilde{p}]+Var[\tilde{y}]\cdot Var[\tilde{p}-\tilde{r}]+2\cdot h\cdot Var\left[\frac{\tilde{r}}{2}\right]\cdot E[\tilde{y}]$$
$$=Var[\tilde{y}]\cdot E[(\tilde{p}-\tilde{r})]^2+Var[\tilde{p}]\cdot(E[\tilde{y}]-h)^2$$
$$+Var[\tilde{r}]\cdot E[\tilde{y}]^2+Var[\tilde{y}]\cdot Var[\tilde{p}-\tilde{r}]$$
$$=\sigma_e{}^2\cdot(\bar{p}-\bar{r})^2+\sigma_p{}^2\cdot(f-h)^2+\sigma_r{}^2 f^2+\sigma_y{}^2\cdot\left(\sigma_p{}^2+\sigma_r{}^2\right)$$

VIII. References

[1] P. Klemperer, "Auction Theory: A Guide to the Literature," *Journal of Economic Surveys*, vol. 13, no. 3, pp. 227-286, July 1999.

[2] P. Cramton, "The Efficiency of the FCC Spectrum Auctions," *Journal of Law and Economics*., vol. 41, no. 2, pp. 727-736, October 1998.

[3] P. Milgrom, "Putting Auction Theory to Work: The Simultaneous Ascending Auction," *The Journal of Political Economy*, vol. 108, no. 2, pp. 245-272, April 2000.

[4] W. Vickrey, "Counterspeculation, Auctions, and Competitive Sealed Tenders," The *Journal of Finance*, vol. 16, no. 1, pp. 8-37, March 1961.

[5] L. Greismer, R. Levitan and M. Shubik, "Towards a Study of Bidding Processes Part IV: Games with Unknown Costs," *Naval Research Logistics Quarterly*, vol. 14, pp. 415-434, 1967.

[6] R. Wilson, "Competitive Bidding with Disparate Information," *Management Science*., vol. 15, no. 7, pp. 446-448, March 1969.

[7] J. Bulow and P. Klemperer, "Auctions Versus Negotiations," *The American Economic Review*., vol. 86, no. 1, pp. 180-194, March 1996.

[8] S. Matthews, "Comparing Auctions for Risk Averse Buyers: A Buyer's Point of View", *Econometrica*., vol. 55, no. 3, pp. 633-646, May 1987.

[9] R. Epstein, L. Henríquez, J. Catalán, G. Weintrub, C. Martínez, "A Combinational Auction Improves School Meals in Chile," *Interfaces*, vol. 32, no. 6, pp. 1-14, December 2002.

[10] Trade extensions, "Business Case: Saving Money for Volvo with a Combinatorial Auction," www.tradeextensions.com, 2001.

[11] A. Kahn, P. Cramton, R. Porter, and R. Tabors, "Pricing in the California Power Exchange Electricity Market: Should California Switch from Uniform Pricing to Pay-as-Bid Pricing?," *Blue Ribbon Panel Report*, California Power Exchange, January 2001.

[12] J. Bower and D. Bunn, "Experimental Analysis of the Efficiency of Uniform-Price versus Discriminatory auctions in the England and Wales Electricity Market," *Journal of Economic Dynamics and Control*, vol. 25, pp. 561-592, March 2001.

[13] G. Xiong, S. Okuma, H. Fujita, "Multi-agent Based Experiments on Uniform Price and Pay-as-Bid Electricity Auction Markets," 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, Hong Kong, April 2004.

[14] H. Rudnick, S. Mocarquer., "Contract auctions to assure supply adequacy in an uncertain energy environment", IEEE Power Engineering Society General Meeting, Montreal, Canada, June 18-22, 2006

[15] R. Moreno, L. A. Barroso, H. Rudnick, S. Mocarquer, M. Bezerra, "Auction Approaches to Ensure Resource Adequacy in Electricity Markets", submitted to IEEE Transactions on Power Systems, 2007

[16] J. Chavas and P. Rulon, "Hedging and Production Decisions under a Linear Mean-Variance Preference Function," *Western Journal of Agricultural Economics*, vol. 7, no. 1, pp. 99-110, July 1982.

[17] CNE Resolución Exenta Nº 704. Texto definitivo de plazos, requisitos y condiciones para las licitaciones de suministro de energía, Santiago Chile, 2005.

[18] CNE Fijación de Precio Nudo Abril de 2007. Sistema Interconectado Central, Santiago, Chile, 2007.

[19] Law Nº 20.018, Modificaciones a la ley DFL N° 1, Ministerio de Economía Fomento y Reconstrucción de Chile, Santiago, Chile, 2005.

[20] F Caravia y E. Saavedra, "Subastando la Energía Eléctrica para Clientes Regulados: Equilibrio con Información Completa y Aversión al Riesgo," Cuadernos de Economía, vol. 44, no. 129, pp. 3-30, May 2007.

IX. Acknowledgements

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X. Biographies

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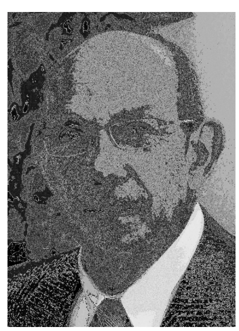

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