AN ELECTRICITY MARKET DESIGN FOR RENEWABLE ENERGY[1]

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Overview

Renewable generation presents very different cost and risk structures compared to traditional fossil-fuel thermo power generation. Given the shift from fossil-fuel to renewable generation that is underway worldwide, policy makers must examine how to adapt electricity market design to cope with the intricacies associated to renewable generation technologies. Brazil's electricity market design also requires adaptations, but it provides a good case study from which to examine the issue given that it has always been predominantely supplied by renewable generation. Four key features are identified as being fundamental for properly functioning renewable energy markets: (i) a long-term contracting market to coordinate investment decisions, (ii) a secondary market to promote adjustments to current conditions, (iii) regulation to ensure uniform long-term resource adequacy and security and (iv) clearing of all transactions in the spot market to ensure market players' payments are based on actual performance and needs given prevalent market conditions.

Keywords – electricity market design / renewable generation / hydroelectric systems

1. The Renewable Energy Challenge

The electric power industry is undergoing a major shift away from fossil-fuel generation to renewable generation. The shift is driven by environmental policies to reduce fossil-fuel emissions and by energy security policies aimed at decreasing the dependency of nonrenewable resources that are often imported and subject to wide price fluctuations.

The shift has been promoted by a combination of "push" and "pull" policies. The "push" policies are those discouraging fossil-fuel technologies (i.e. taxation of fossil fuels, taxation of emissions, stricter environmental standards, compulsory closures…) and the those "pull" policies are promoting renewable generation (i.e. subsidies, feed-in tariffs, quota obligations…).

As a result, the participation of renewable energy in the generation mix has gradually increased. The process has also helped lower costs of renewable technologies. It is now widely accepted that large deployement of renewable generation is not only technically feasible but likely to play a major role in the electric power industry in the coming decades. The issue then is what will be the consequences of the large deployment of renewable generation and what are the market design changes that are needed to support renewable generation in the long run (Moselle, Padilla and Schmalensee, 2010).

1.1 Traditional Market Design

The design of most electricity markets has been shaped by the needs of fossil-fuel thermo generation. In thermo systems the primary sources of uncertainty originate from operational contingencies, fuel cost variability and demand variability. Since thermo power plants can be dispatched upon demand, generating capacity is fully controlled variable. Demand variability and operational contingencies can be dealt with by establishing operating reserves suficient to deal with these uncertainties (Meyer, 1975).

To deal with the fuel cost variability, electricity markets have generally been structured with the spot market playing a central role. The operation is based on short-term bids from power plants (generally in a "day-

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ahead" market), based on their current marginal costs, which ensures variable cost minimization (as long as there is sufficient competition in the market).

In the investment stage, the main challenge faced in thermo systems is to define the optimal mix of power plants based on their respective combination of fixed and variable costs. Base load is optimally met by power plants that present the lowest average costs for high load factors, which is obtained by tecnologies with low variable costs (and comparatively high fixed costs), while peak demand is optimally met by additional generation coming from power plants with low fixed costs (and high variable costs). Again, optimization is generally satisfied by the spot market: power producers decide in what type of plant to invest based on the load duration curve and on the expected revenue stream given the spot market price patterns (Oren, Smith and Wilson, 1985).

1.2 Characteristics of Renewable Energy Generation

Renewable generation technologies present a completely different cost and risk structure which give rise to a completely different market. Unlike fossil-fuel thermo power plants – in which variable costs play a central role – renewable generation technologies have negligible variable costs, which implies they are free of fuel-cost uncertainty, but they are not risk free, for their generating capacity is contrained by the stochastic availability of the natural energy resource. These two features have profound implications for electricity markets.

1.2.1 Negligible Marginal Costs

Marginal costs are key features in electricity spot markets. Fossil-fuel thermo plants will not operate unless the spot price is equal or higher than their marginal costs. Thus their marginal costs serve as "price anchors" on which market players project how often their plants are likely to operate and calculate the expected spot market revenue flows. Although fossil-fuel costs fluctuate considerably overtime, the different fuels (and consequentely the variable costs of the thermal power plants) tend to be positively correlated, which makes electricity operation relatively predictable.

Because renewable generation has negligible marginal costs, they dislocate more generation from power plants with higher marginal costs, lowering previously expected spot market pricing and capacity factors of existing power plants. Pérez-Arriaga and Battle (2012) refer to this phenomenon as the "merit order" effect. Not only does the increasing share of renewable generation depress spot market prices, but it also increases the cycling of incumbent thermo power plants, resulting in higher operating costs (increased start-up and cool-down costs) and increased wear and tear of equipment.

As renewable generation becomes predominant, the possibility that at any given time the marginal bid in the spot market comes from a renewable generator increases, in which case spot prices collapse to zero. As a result the recovery of the sunk investment costs becomes increasingly dependent on sales during price spikes that occur in periods of scarcity, which may not occur on a regular basis, aggravating the "missing money problem" identified by Cramton, Okenfels and Stoft (2013). The result is that the long-run income stream derived from sales in the spot market may no longer provide a reliable source of revenue to recover the power plants' sunk investment costs. It may also become an inappropriate reference for pricing long-term supply contracts.

1.2.2 Stochastic Supply

Another fundamental difference between the different technologies is their ability to control production over time. Thermal power plants can produce on-demand up to their installed capacity. Renewable generation, on the other hand, is constrained not only by the installed capacity, but also by the availability of the natural energy resource that powers the technology.

This difference alters system planning fundamentally. In fossil-fuel thermo systems adequacy is assured when enough capacity is installed to meet peak load, considering generation and transmission contingencies. Resource adequacy is much more difficult to ascertain with renewable generation, because it depends not only on installed capacity, but mainly on the stochastic availability of the natural energy resources.

Natural energy resource availability is not entirely random, however; each natural energy resource has a unique pattern, which typically varies in seasonal and daily cycles. This gives rise to complementarities, by which different renewable generation technologies – or the same technologies located in different areas – can be combined to better meet the load requirements at each moment in time.

An ideal market design for renewables should provide incentives that enable coordination of investment in these different supply alternatives to assure resource adequacy at least cost. This involves providing price differentiation between relevant periods ("state-contingent pricing") or adopting structural arrangements to ensure reliable consistent supply over all states (Ambec and Crampes, 2012).

The variability of supply from renewable generation adds to the uncertainty associated with forecast demand. This increases the importance of price responsiveness both from other generators and from consumers. This accentuates the importance of sufficiently detailed spot market pricing to enable differentiation of prices between times and locations. Thus, it is crucial that spot market pricing is sufficiently granular to capture these relevant price differentials (Wolak, 2003).

A common problem in electricity markets is that some of electricity consumers do not respond to wholesale spot market prices. For these customers it is optimal for system operators to promote rationing when spot prices surpass their estimated value of loss load (Joskow and Tirole, 2007). This issue is exacerbated when supply variability from renewable generators is added to demand variability.

2. Brazil's Electricity Market Experience

The Brazilian electricity market provides an interesting backdrop to study electricity market design for renewables since renewable generation has always been prominent in the Brazilian power industry.

Brazil's electricity supply is provided primarily by hydroelectric power plants and in recent years a large share of generation expansion has come from wind power and biomass thermo power plants. In coming years solar generation is also expected to become an increasingly important power source.

Hydro reservoirs enable arbitrage between different time periods, which greatly facilitates the handling of short-term intermittency of other renewable energy forms, such as wind and solar power. This mitigates the problems associated to intermittency, which is a key concern in thermo based power systems. Nevertheless, the natural energy resource supply variability remains a central issue in Brazil's power industry, but on a different time frame. Rather than short-term intermittency, Brazil's most relevant natural resource variation occurs on a yearly time frame. Hydro inflows (i.e. the amount of electricity that can be produced by hydroelectric plants with the available water inflows) can vary more than 100% from one year to another.

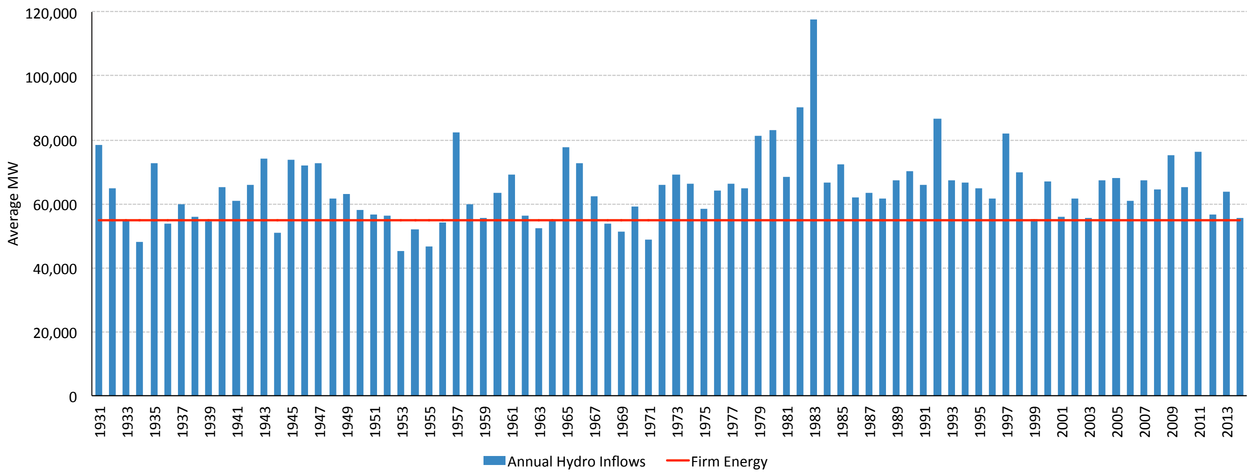

Figure 1 – Aggregate Annual Hydro Inflows and Firm Energy (source: ONS and Aneel)

Given the negligible marginal costs of hydro generation, in most years spot market prices can remain very low, but occasionally can reach (and sustain) extremely high levels during dry years. In years of average or above-average rainfall, spot market prices are insufficient to recover sunk investment costs and in years of below-average rainfall prices reach extremely high levels that may be difficult for market participants on the buyers' side of the market to pay.

The most challenging aspect, however, is the irregularity of occurrence of these periods of abundance and scarcity: decades may go by with abundant supply, then suddenly two or three years in a row of extreme drought may occur.

2.1 Key Features of Brazil's Current Market Design

To deal with these challenges, the long-term contracting market was made the centerpiece of Brazil's electricity market. Furthermore, stringent regulation was put in place to ensure resource adequacy.

2.1.1 Firm Energy Certification (Garantia Física)

To ensure resource adequacy Brazil has adopted a system of certification of the Firm Energy (*Garantia Física*) of each power plant. The amount of energy generators are allowed to sell in the form of long-term contracts is capped by the amount of Firm Energy. All wholesale customers are required to contract 100% of their needs, so as to ensure adequate supply.

The Firm Energy is determined by mathematical modeling considering historical hydro inflows so as to determine the amount that can be consistently supplied at a given reliability level. The resulting Firm Energy is less than the average annual hydro inflows, thus in periods of regular or above-average rainfall the system capacity (available energy) exceeds demand. This is a feature that will likely be present in all electric systems in which renewable generation becomes the main source of generation.

2.1.2 Forward Contracting in Energy Auctions

To facilitate system expansion and stabilize revenue flows, Brazil has structured the long-term contracting process to meet the needs of regulated retail customers serviced by distribution companies by means of two set of auctions:

- "New Energy Auctions" are held to contract energy to meet forecasted demand growth; and
- "Existing Energy Auctions" are held to contract energy to replace expired contracts.

The New Energy Auctions are held three to five years ahead of the supply date so as to enable entrepreneurs to compete for future supply based on projects of power plants yet to be built. The contract duration is for 20 to 30 years. Prior to the auction, each distribution company submits its projected demand growth to the government entity responsible for the execution of the auction. The aggregate demand needs of all distribution companies is then met in a descending price auction in which the winners' bids set the price at which the energy will be sold (with annual adjustments for inflation). At the end of the auction, contracts are established between each of the generators with winning bids and each of the purchasing distribution companies.

The New Energy Auctions practically eliminate entry barriers, establishing a contestable market, which ensures competitive long-term pricing. The New Energy contracts also provide firm purchase commitments that virtually eliminate market risks for investors in new power plants, which greatly facilitate project financing.

The Existing Energy auctions are held annually to replace contracts that are expiring at the end of the current year. Contract durations are for periods of 3 to 15 years. The contract prices are also established by descending price auctions and adjusted annually for inflation.

Both the New and Existing Energy contracts are strictly financial contracts (contracts for differences).

The brunt of the market risk is borne by the distribution companies and their customers that are exposed to the effective take-or-pay conditions of the New Energy contracts, and on suppliers of Existing Energy, whose contracts have shorter duration and have clauses that allow the purchaser to partially reduce contracted quantities. When demand growth is less than previously forecasted, the adjustment falls upon Existing Energy generators who are then forced to sell their energy at a low prices or remain idle. The burden of frustrated demand growth projections also falls upon distribution companies and their regulated customers, who must honor previously contracted energy obligations regardless of their effective consumption. Likewise, when demand growth is greater than previously forecasted, distribution companies and regulated customers must bear the cost of scarcity rents, purchasing additional energy in the spot market.

2.1.3 Tight Pool

Because of the complexity of stochastic intertemporal optimization of hydrothermal power system and its many interdependencies (externalities), policy makers opted to preserve centralized control of system operation and spot market pricing. Thus the "tight pool" arrangement was preserved, with the System Operator being responsible for determining optimal dispatch of all power plants, following a well defined set of procedural rules, and spot market pricing determined by the same official computer programs used by the System Operator.

The ensuing market design, gives market players little autonomy: generators and retailers manage the contracting of available Firm Energy based on expectations on how the system will be operated and on spot market pricing. Distribution companies have even less autonomy, since their long-term contracting is procured by the governmental energy auctions.

2.2 Concerns that Arise from Brazil's Experience

While Brazil's market design was conceived to deal with the challenges associated with widespread renewable generation, it has a number of shortcomings that are becoming increasingly evident. Four major areas are of particular concern when designing the market for renewable energy: (i) coordination of investment decisions, (ii) risk management, (iii) resource adequacy and reliability, and (iv) system operation.

2.2.1 Coordination of Investment Decisions

Brazil's Energy auctions have been quite sucessful in promoting competition and investment in new power plants (Moreno *et alii*, 2010). Over time it has become increasingly clear, however, that the Energy Auctions have a few weaknesses, particularly with regard to the appropriateness of the mix of power plants aggregated to the system. First, energy auctions promote contracting of new power plants based solely on the price at which they are willing to offer their Firm Energy. Other important aspects – such as the power plant's location, operational flexibility and ability to dispatch upon request – are not directly taken into consideration.[2] These neglected aspects can result in suboptimal investment. Second, the computer models used to determine the fixed energy have numerous shortcomings which distort competition in the energy auctions. Third, the auctions do not take into account how the mix of power plants offered in the auction affect each other. The Firm Energy certificiation prior to the auction only takes into account how the plant would operate given the existing power plants, but neglects how other power plants offered in the same auction will impact each other's operation. It also neglects how operation is expected to change given likely expansion of future generation.

These factors distort the resulting mix of power plants procured in the energy auction process, resulting in higher costs or lower reliability levels.

2.2.2 Risk Management

Brazil's current market design rightly focuses on structuring the market for long-term contracting – a crucial feature of market design for renewable generation – but it presents major difficulties in promoting the needed adjustments to effective conditions. Subsequent changes in demand growth, availability of the natural energy resources, power plant productivity, dispatch patterns, operational costs, for example, are not

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[2] Some of these features are indirectly taken into account in the computer modeling used to establish each power plant's Firm Energy certification. The Firm Energy is based on price-weighted average supply considering the existing power plants and hydro inflow scenarios built based on statistical characteristics of historical data.

readily adjusted for in the current market design, which increasingly distorts system operation and pricing. These distortions eventualy lead to regulatory interventions and litigation, which increases regulatory risks.

The current market design not only lacks market mechanisms for players to adjust to current conditions, but also fails to provide adequate incentives for market participants to make the needed adjustments to current conditions.

Because market participants do not dispose of proper means to manage this risks, regulatory or judicial disputes often result in the socialization of costs incurred, which further weakens market participants incentives.

2.2.3 Resource Adequacy and Reliability

One of the key concerns that arises in electricity markets is how to ensure resource adequacy and system security. When the responsibility for supply is no longer attributed to a single entity, market mechanisms must be established to ensure the desired reliability level.

The requirement that all wholesale consumers be fully contracted mitigates this concern, but is not perceived as being entirely sucessful in ensuring long-term resource adequacy in the Brazilian electricity market.

Individual consumers are unable or unwilling to contract many years in advance. Thus new capacity is supported primarily by the New Energy imposed on regulated customers that are serviced by the distribution companies. Furthermore, given the characteristics of Brazil's predominantely hydro system, most of the time there is ample energy available for short-term contracting in very favorable terms for the buyer. In periods of scarcity one expects these consumers would be exposed to very high prices, but this effect is minimized by the fact that in a severe drought, rationing would most likely be imposed on all customers, which socializes the risk exposure among all consumers. Thus, consumers that chose to join the wholesale market "free ride" the system by leaving the rest of the market bear the cost of long-term contracts needed to ensure system expansion.

This weakness is one of the factors that has halted further liberalization of the Brazilian electricity market (currenly only customsers with a demand of 500 kW or more can opt to procure their own supply in the wholesale market). Policy makers fear that if the share of the regulated market were significantly diminished system expansion promoted by means of the New Energy Auctions could be jeopardized (regulated customers serviced by the distribution companies currently corresponds to roughly 75% of the consumption in Brazil's electricity market).

2.2.4 System Operation

While market players understand the complexity involved in system operation and generally show an appreciation of the sophisticated mathematically modeling employed to promote system optimization, there is increasing awarness of a number of the shortcomings of system modelling and of the System Operator's dispatch decisions. There has been increasing number of complaints regarding the quality of input data and parameters used in the system modeling; there is mounting criticism regardomg the mathematical modeling methodology; and there is increased consternation regarding discretionary operating decisions made by the System Operator. Brazil's power mix is undergoing major changes; profound modifications are needed in operating procedures to deal with this new reality.

Yet in Brazil's current market design, market participants must make long-term commercial transactions based on expectations on how the system is going to be operated and how spot market transactions are going to be priced. Given market players have no control over operation and spot market pricing, it is crucial that the dispatch policy and spot market pricing be stable and predictable.

The need to adapt to the new reality on the one hand, and the need to maintain stability and predictability, on the other hand, are conflicting objectives that remain unreconcilable in Brazil's current market design.

3. An Electricity Market Design for Renewables

The electricity market design proposed in this paper marks a shift from what Wilson (2002) refers to as an "integrated" paradigm to the "unbundled" paradigm. The integrated paradigm seeks to imitate vertically integrated operation by structuring an elaborate centralized market that explicitly prices all costs and constraints from which the market mechanism seeks to optimize system operation. The unbundled paradigm, on the other hand, takes a "second-best approach", which acknowledges that some productive inefficiency losses due to decreased system coordination may be needed to achieve a more robust incentive structure for market participants.

The market design proposed in this paper seeks to meet four fundamental needs of renewable power markets by a sequence of markets.

First, given that optimization of renewable generation depends fundamentally on the investment choices, market design should establish mechanisms that facilitate long-term contracting so as to provide long-run marginal price signals and long-term commitments. This enables proper exploitation of complementarities between different generation technologies and locations and helps promote risk sharing between market participants, enabling them to better withstand supply and demand shocks. It also mitigates the risk of market power abuse.

Second, market design should foster the development of a secondary market to facilitate the adjustment of long-term positions to current market conditions. This can be achieved by the adoption of standardized contracts (energy certificates) so as to minimize transaction costs and increase liquidity. It is also fundamental that these standardized energy certificates be differentiated by relevant features (from the perspective of system needs), so as to provide proper price signals to guide investment decisions.

Third, market design must ensure long-term system resource adequacy and security. This is a public good whose cost should be uniformly funded by all market participants. If market rules are not imposed in a competitive environment to ensure uniform system adequacy and security, more risk-loving firms will tend to systematically underbid more prudent firms, leading to a "race to the bottom" of deteriorating system adequacy and reliability.

Fourth, market design should ensure that remuneration of market participants be ultimately based on actual performance and effective market conditions. This requires that all transactions ultimately be cleared in the spot market. It also requires that the spot market capture all relevant cost determinants. This ensures proper incentives for market players to seek to meet system effective needs.

3.1 Forward Energy Supply Auctions

Forward contracting by means of centralized auctions to meet future demand is an attractive feature of Brazil's current market design which is maintained in this proposal with a few changes. The use of auctions to contract future power supply several years in advance, so as to enable the participation of existing power producers (with existing power plants) and of entrepreneurs (with pre-approved projects of power plants yet to be built) is an effective way to foster a perfectly contestable market as defined by Baumol, Willig e Panzar (1982). This significantly diminishes the risk of market power abuse, helps foster efficient expansion and the mitigation of risks for power producers and consumers.

The long-term commitments established in the contracts sold in these auctions enable market participants to make long-term investment decisions based on current market expectations. As long as the firms fulfill their commitments, the suppliers' revenues and purchasers' costs will be those established by the contractual terms. This greatly decreases market uncertainty, facilitating log-term investment decisions.

The electricity contracts would be procured by means of descending price auction in which power producers would compete to obtain forward energy contracts. Purchasers could also participate in the auction increasing their demanded quantity as prices decrease.

The auctions and standardized contracts would be organized by the regulatory agency. Unlike Brazil's current Energy Auctions, participation in the auctions would be open to all power producers (i.e. no segregation of New and Existing Energy producers) and consumers (i.e. no segregation of regulated and free consumers) and participation in all auctions would be strictly voluntary.

3.2 Standardized Contracts

Given the stochasticity of supply and demand, and the subsquent wide-price swings due the low price elasticity of short-term demand, electricity markets are very susceptible to boom and bust cycles. The key to stabilizing the market, in both periods of abundance and scarcity, is to have market participants anticipate future conditions.

One way to do this is to foster long-term contracting. Long-term contracts not only helps stabilize revenue streams, but also facilitates investment decision, thus sharing risks through long-term commitments made betweem purchaser and buyer.

However, more precise operational decisions can only be made as one approaches the delivery date as better information on prevailing supply and demand becomes available. This is especially relevant for renewable generation sources that depend on weather conditions (rainfall, wind, sunlight, crop yields…). To reconcile the long-term positions with the more refined decision-making that is made possible as one approaches the delivery date, market players can make adjustments in the secondary market by purchasing or selling portions of existing contracts.

To foster a vibrant secondary market, standardized contracts should be promoted. Standardization of contracts increases market liquidity and reduces transaction costs by enabling players to adjust their market positions by the purchasing or selling additional units of interchangeble contracts (Energy Certificates).

Two major types of standardized contracts could be established to meet the needs of the various generation technologies: Energy Certificates and Call Options. These would be financial obligations, which would be cleared together with spot market transactions.

3.2.1 Energy Certificates

Energy Certificates are contracts designed to meet the needs of renewable generation technologies. Since these technologies typically present negligible marginal costs, the most relevant information is the amount of energy that the power plant can reliably produce at each relevant time period.

As pointed out by Castro, Negrete-Pincetic and Gross (2008), product definition is of central importance in market design, an aspect that has been often overlooked in the literature. Proper product definition provides better price signals and risk allocation, which can significantly improve market performance. Thus Energy Certificates should be differentiated based on the main supply and demand characteristics.

Demand varies significantly over the course of each day and season of the year. Thus it may be convenient to differentiate the Energy Certificates based on the shape of the load curve: differentiated daily into peak and off-peak, and seasonally into summer and winter.

On the supply side, differentiation should take into consideration the natural energy resource patterns. For example, in a system in which solar generation is prevalent, energy certificates may be segmented based on time intervals of different intensities of solar radiation: high (near noon), low (early morning and late afternoon) and night.

The key in delineating the different Energy Certificates is to capture the key features needed to provide proper investment incentives.

For example, in Brazil's case, in which hydroelectric generation prevail, segmentation should de based on rainfall seasonal patterns:

- wet; and
- dry.

The greater the price differentiation between wet and dry season, the more attractive it will be to invest to in reservoirs to regulate hydro inflows between seasons.

A differentiation between peak and off-peak may also be desirable to incent generators to install more turbines, in order to be able to concentrate generation during periods of peak demand. In more general terms, one could differentiate between:

- “modular supply”; and
- “base supply”.

While “base supply” is production capacity which is constant in time, “modular supply” would enable concentrating generation in periods of greater demand, which is convenient to meet not only peak demand, but also to meet the demand derived from intermittent generation. Modular supply contracts give the buyer the prerogative of defining how the quantity of energy contracted is to be distributed in particular blocks of time, within specified modulation limits. To supply modular energy contracts, the power plant must be dispacthable upon request and the ratio of Firm Energy to installed capacity is sufficient to meet the modulation requirements.

Another relevant dimension for product differentiation is location. In systems where transmission constraints are limited, well defined zones may be identified where prices are relatively uniform. This has been considered the case of Brazil, in which the major transmission constraints are limited to interconnections between four subsystems. These are natural candidates to be a third dimension by which to differentiate the Energy Certificates:

- North;
- Northeast;
- Southwest / Center-West; and
- South.

These different Energy Certificates would be sold simultaneously in the forward energy auctions. Generators would bid based on overall revenues expected given the mix of different types of energy certificates their power plant is expected to reliably supply. Buyers would specify the amounts desired of each type of Energy Certificate.

The price differentiation of the energy certificates would favor the contracting of power plants that are best suited to meet the system marginal needs. It would also provide useful price signals for entrepreneurs to seek out new power projects for upcoming auctions.

Although the market risk associated by the sale of energy certificates would be solely borne by the power plant that issues the certificate, the issuance of new certificates would be regulated by a governmental agency, so as to cap the maximum sale of certificates that can be sold by the power plant based on the plants capacity considering minimum reliability criteria.

3.2.2 Call Options

Thermo power plants are best dealt with Call Options. The consumers would pay a monthly premium for the Call Option sold by generators. Every time spot market prices surpass the Call Option’s strike price, the generator would be called upon to meet the consumer’s needs (either paying the difference between the spot and the strike price or by producing the contracted amount for the specified strike price). This arrangement eliminates the market risk for generators, since competitive Energy Auctions should lead to monthly premiums that are sufficient to cover the Thermo power plant’s fixed costs while the strike price should be sufficient to cover their marginal costs.

Renewable technologies that have intermittent generation would have three options to handle the risk derived from the intermittence of its natural resource:

1. sell Energy Certificates equivalent to the amount the power producer deems possible at the given reliability level and deal with the intermittence by means of spot market transactions, considering

the expected revenues earned from surplus generation in periods the intermittent source produces more than its contractual obligations and the costs incurred in purchasing energy in the spot market in periods it produces less than contracted amounts;

2. sell Energy Certificates equivalent to the amount the power producer deems possible at the given reliability level coupled with Swap Contracts purchased from power producers with modular supply, by which intermittent generators can effectively trade energy produced in certain periods for energy to be delivered in other periods;
3. sell Energy Certificates equivalent to its installed capacity coupled with Call Options, which would enable intermittent generators to complement their supply with electricity produced from thermal power plants at a pre-established price in the Call Options.

These different contract modalities not only meet the different needs and characteristics of each generation technology, but also provide consumers means to manage their energy supply risk. Both types of contracts ensure supply and cap market prices, the difference being that Energy Certificates specify exactly how much the electricity will cost, while Call Options allow consumers purchase electricity at spot market prices, while capping their maximum exposure, which enables them to exploit the lower prices during periods of abundant power supply, without becoming exposed to extremely high prices during periods of scarcity.

All Energy Certificates and Call Options would be registered, cleared and settled in a centralized market. The central market would make information on the systems' aggregate supply and demand conditions more easily accessible and reduce transaction costs.

3.3 Market Maker

To ensure resource adequacy a "Market Maker" would be established. The Market Maker would be an independent entity that would be responsible for long-term contracting of additional energy to ensure the needed expansion of supply, as to ensure resource adequacy and security at the desired reliability level.

Each year the electricity regulator (or other government designated entity) would evaluate supply and demand conditions three years ahead. When supply is deemed insufficient to meet future forecasted demand at the desired reliability level, an auction would be setup to contract energy for delivery three years ahead. Power producers would compete in descending price auction to obtain the forward energy contracts. The Market Maker would be the purchaser of the contracts. The Market Maker would subsequently make the energy available in the secondary market with shorter lead times and contract durations, and any remaining energy contracted by the Market Maker would be made available in the spot market.

The Market Maker would follow pre-established commercialization procedures and pricing directives. The Market Maker's pricing policy should include a mark-up rule to cover the risk it assumes in the market-making function. In case the Market Maker comes to experience revenue shortfalls, a fee would be levied on short-term contracts and spot market transactions to cover the deficit. Fees would be levied so as to ensure that the Market Maker's costs are predominantly borne by the customers that effectively rely on it for supply.

The Market Maker would thus ensure system expansion in order to maintain security of supply. It would also help ensure market liquidity and serve as an anchor for market pricing.

Eventually it is likely that some market participants would seek to compete with the Market Maker, building or contracting power supply in advance at their own risk, to sell to these consumers that cannot or prefer not to contract energy with such long lead times.

3.4 Two-Settlement System

Operation and spot market pricing would no longer be determined by the System Operator and official computer models, but rather based on bids submitted by market players in the spot market. This would provide more operational autonomy to power producers as well better incentives for market participants to actively seek to optimize operations.

The spot market would take the form of a two-settlement system – the first settlement being that of the day-ahead market which would determine the dispatch order for the following day (with possible adjustments for electricity constraints), and the second settlement would be done *ex-post* (i.e. after operation) based on the differences between the predefined dispatch order and the effectively observed amounts of energy supplied and consumed by each market participant.

The two-settlement system is the leading paradigm for electricity spot market. It enables the system operator to plan daily dispatch in a very similar way as it is done in command-and-control environment. It provides proper incentives for power producers to make all their capacity available to meet the system needs and consumers to decrease consumption when the price surpasses the value they attribute for electricity. It also fosters competition between producers, by which market forces can discipline prices.

It is critical that the spot market capture all relevant cost determinants. This can be achieved by increasing spot market price granularity both temporally and spatially to enable relevant price differentiation. Most spot markets partition the daily market into half-hour intervals or less. Although zonal pricing may be adequate if transmission constraints are not prevalent in a particular region, "locational marginal pricing" is the safest bet for market design, since it automatically adjust prices at each node of the transmission system based on current transmission constraints.

4. Discussion and Conclusion

The market design proposed seeks to address both the needs of renewable generation and the problems that have arisen in Brazil's electricity market.

In the market design proposed forward energy auctions allow entrepreneurs to base their decision to invest in a new power plant based on the availability of forward energy contracts that fix prices and quantities for many years in advance. This arrangement greatly minimizes generation risk by shifting market risk to consumers. It not only protects producers from demand risk, but also from the "merit order" risk due to subsequent entry of other generators.

Furthermore, the equilibrium prices obtained in the forward energy auctions are the long-run marginal costs (long-run average incremental costs) of generation that provide total cost recovery (of both variable and fixed operating costs), thus averting the "missing money" problem.

It is expected that most of the revenue stream between consumers and producers would be determined by long-term contracts closed in the forward energy auctions.

If auction product differentiation (types of contracts) is appropriately defined, relative prices should promote the optimal mix of power plants, enabling full expoitation of complementarities between different technologies and locations.

Of course power producers that employ renewable generation will not offer all of their capacity in the forward energy auctions because of the natural resource stochastic supply, so that a portion will continue to be supplied nearer to the delivery date, when actual natural resource availability is known, by means of shorter term contracts or in the spot market.

The secondary market for standardized contracts in the form of Energy Certificates will provide market participants with the effective instruments to adjust their contractual positions as new information is made available, thus optimizing the system operation.

The Market Maker would ensure resource adequacy and reliability without imposing stringent regulation and contracting requirements on market players.

The spot market bid-based pricing and dispatch would enable generators to better manage risks and provide a more robust incentive structure to foster efficient operation.

While this market design might give rise to some operational distortions due to market incompleteness, it would provide a better incentive scheme for market participants, which in the long run is likely to provide significant efficiency gains to the electricity market. Furthermore, market design would provide better risk allocation and risk management instruments, which would allow the market to automatically adjust to supplly and demand shocks, thus reducing the need for regulatory interventions and litigation.

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