

Capacity Markets in Hydro-Intermittent Dominated Systems*

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1 Introduction: The Problem of Decentralized Hydro Systems

Electricity markets have traditionally been operated in a centralized manner. Since the 90s, many places have shifted gears and the world has been on a clear path towards liberalization, privatization and decentralization of these markets. The electricity market is notoriously complex, and there have been many setbacks in this decentralization process.

One crucial aspect of this market that has been largely discussed is the fact demand does not respond sufficiently quickly to surges in prices. This creates a problem that has been labeled “missing money” (see, for example, Cramton et al. [1]): the supply becomes scarce and the demand is inelastic in the short run, so the market does not clear and there is a shortage of electricity. In a centralized market, this is not an issue: the system constructs excess capacity that operates on those scarcity periods. With private markets, this becomes a serious concern and threat for the reliability of the system: the capacity that should be built for these periods of scarcity will not receive the appropriate payment (due to the missing money) to induce their entry.

A system that is predominantly hydro suffers even more from the missing money problem. Hydro electric generators depend on the availability of water, a stochastic and non-marketable input. In a decentralized market, these hydro producers are playing a dynamic game in which they are constantly deciding whether to use their storable input. When there is excess water in the system, prices are low, inducing some of these generators to save water for a possible future use they might face a scarcity period, meaning high prices. This trade-off between current and future use of water helps to balance the system by inducing generators with large reservoirs to transfer water from rainy periods to dry periods, alleviating those scarcity periods. Because of the missing money problem described in the previous paragraph, periods of scarcity will not face the high prices that would be required to clear the market. This decreases the incentives for generators with reservoirs to store water: the future high prices might not compensate the waiting period. There is less smoothing in the system. Therefore, the missing money problem is severe for two reasons: decreases incentives for investment in low-fixed-cost and large marginal costs technologies that would only operate in the much-needed scarcity periods and decreases the incentives for hydro generators to smooth their production.

A second issue with hydro dominated system is that water and clean energy such as sun and wind are intermittent and with very low operating costs. On top of that, many hydro sources are run-of-river production and clean energy is by and large not storable with the current technology. In economic terms, what this means is that in periods of sun, wind or rain, electricity in systems dominated by these sources will be very cheap. These low prices reduce further the incentives for other technologies to enter the market. Indeed, if clean energy is only induced to enter the market through subsidies, the higher the proportion of clean energy in the supply of the system, the more expensive it becomes to induce additional clean sources to enter. This phenomenon is

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known as the clean energy paradox. The low prices imply that thermal sources and other traditional technologies with higher marginal costs will have low incentives to enter, which aggravates further the already problematic issue with the missing money. That is, these technologies with high marginal costs face the following problem in systems dominated by intermittent sources with non-storable stochastic inputs: long periods with low prices and infrequent periods where the scarce supply does not induce high enough prices due to the missing money. The reliability of the system is in serious risk.

Unfortunately, the reliability is not the only issue at risk. A well-known characteristic of energy markets is that given the high fixed costs of generators, investors seek low-risk returns. This is a particularly serious problem in Brazil where the system heavily relies on hydro generators and where the financing of these high-fixed costs producers has been historically dependent on state financing, requiring low risk returns.

This brings us to the third and final market failure: reliable high-marginal costs technologies are not environmentally friendly, generating externalities that a private market would fail to internalize. This explains the heavy subsidies to clean energy, as the European example illustrates. We summarize the electricity challenge as follows: tax-payers would like to see a system that is reliable, environmentally friendly and with low prices. Is it possible to have a decentralized market that meets these demands?

Several papers discuss the role of capacity markets.¹ Joskow and Tirole [3] provides a general analysis of the missing money problem and the role of capacity payments. Cramton et al [1] and [2] provide a practical description of economic principles of capacity markets.

2 Traditional capacity market with reliability options

The capacity market is similar to the one described by Cramton et al [1]. As they describe, the regulator procures a target amount C^* of capacity. For most cases, C^* corresponds to the amount of capacity needed some years ahead. For each unit of capacity sold at the auction, generators will be paid the capacity premium c . This premium is defined at the capacity auction.

Along with each unit of capacity procured comes a call option, that the regulator uses every time the spot price rises above a threshold. This threshold is the strike price $p^{ceiling}$. The regulator uses the option to purchase the amount of energy contracted from the generator at the strike price $p^{ceiling}$.

However, systems intensive in intermittent sources have a non negligible risk of facing periods with very low prices. We take into account this feature into the market design described below.

3 Our Proposal: Capacity market with options' band

We propose to include a put option in each unit of procured capacity. There are then two options associated with each unit of capacity: (i) the call option just described, and (ii) a put option that establishes strike price below which every generator earns a hedge payment of $p^{floor} - p^{spot}$.

The call's strike price needs to be set just above the marginal production cost of the least efficient thermal producer. The much lower put's strike price is set at a level that guarantees a minimum cash flow for the generators.

How it works

One fundamental question is whether the capacity premium will be sufficient to attract new investment. Figure 1 shows an hypothetical example of a capacity market at work.

The table on the left displays the spot price for 24 months. In this market, the reliability option has a strike price of 200 for the call and 80 for the put option. The third column on the left hand side table shows the cash flow for a generator that sold one unit of capacity at the auction. Note that on the first months the put option is active, then the call in the intermediate months, and the put again in the two final months.

The net present value (NPV) of the spot market is 3476 and 2833 without and with the reliability options, respectively. We assume fixed entry cost of 1000 and the NPV of an alternative investment of 4500.

This example gives some insights about capacity markets. First, there is no investment in capacity without the capacity market. Second, the capacity premium must be high enough so that it plus the NPV with the options

¹By the term capacity and capacity markets we mean firm energy for hydro and intermittent plants.

tops up the NPV of the alternative investment. In this case, it implies a capacity premium of at least 2667 for investment to happen (or a 118 monthly capacity payment).

Long Term Market				
t	P spot	P w/ options		
1	10	80	interest rates	0.005
2	20	80	CALL strike price	200
3	20	80	PUT strike price	80
4	20	80	NPV spot	3476.0
5	20	80	NPV options	2833.2
6	20	80		
7	50	80		
8	50	80	Fixed entry cost	1000
9	50	80	NPV alternative	4500
10	150	150		
11	150	150		
12	150	150	(i) spot market is not enough to attract investment	
13	400	200	NPV spot < NPV alternative	
14	400	200		
15	400	200	(ii) sell capacity if	
16	400	200	NPV options + capacity premium - fixed cost >= NPV alternative - fixed cost	
17	400	200		
18	400	200	(iii) minimum capacity premium for investment	
19	150	150	capacity premium = NPV alternative investment- NPV options +fixed entry cost	
20	150	150		
21	100	100	capacity premium = 2666.8	
22	100	100	monthly capacity premium = 117.60	
23	70	80		
24	70	80		

Figure 1: Example: capacity market with reliability options

An important point to stress here is that the capacity premium rises enough so that C^* of capacity is supplied.

There are three possible situations concerning the spot price. The first one is when the spot price is between the call and the put's strike prices. In this case none of the options are active and energy is sold at the spot price. The second and third one are when the spot price crosses one of the strike prices.

Figure 2 below shows the path of the Brazilian spot price, called PLD, from 2003 to 2016, with two hypothetical strike prices for the call and put options. Together, the two strike prices form a band, with the call's strike price being the ceiling and the put's strike price being the floor of the band.

When the spot price breaks through the ceiling of the band, it triggers the call options. When it falls below the floor, it triggers the put option. Both strike prices are set in a way that for the most time the spot price fluctuates within the bands

The call option

The second one happens when the spot price rises above the call's strike price $p^{ceiling}$. In this case the regulator uses the call options to purchase the energy at $p^{ceiling}$ instead of paying the now higher spot price, p^{spot} .

We expect this extreme situation to happen when all contracted capacity C^* is sold at the spot market. In this case the winners/sellers of the day ahead market are the ones producing energy, and the regulator uses the call option to get payments of $(p^{spot} - p^{ceiling}) * C^*$ from the contracted generators.

However, there may be situations where the spot price exceeds the call's strike price, but not all the contracted capacity is sold out. In this case, generator i pays the regulator proportional to the load served

$$(p^{spot} - p^{ceiling}) * C^i \frac{Load}{C^*} \quad (1)$$

where C^i is the contracted capacity of generator i and $Load$ is the total load served at the specific time.

The put option

The third situation occurs when the spot price falls below the put's strike price p^{floor} . In this situation the generators may exercise the put option to sell their energy at p^{floor} . In this case, demand is typically low compared to supply capacity. At this point, the relevant question is who are the generators which exercise the put option. The answer is the same as with the call option: generators get paid proportional to the load served

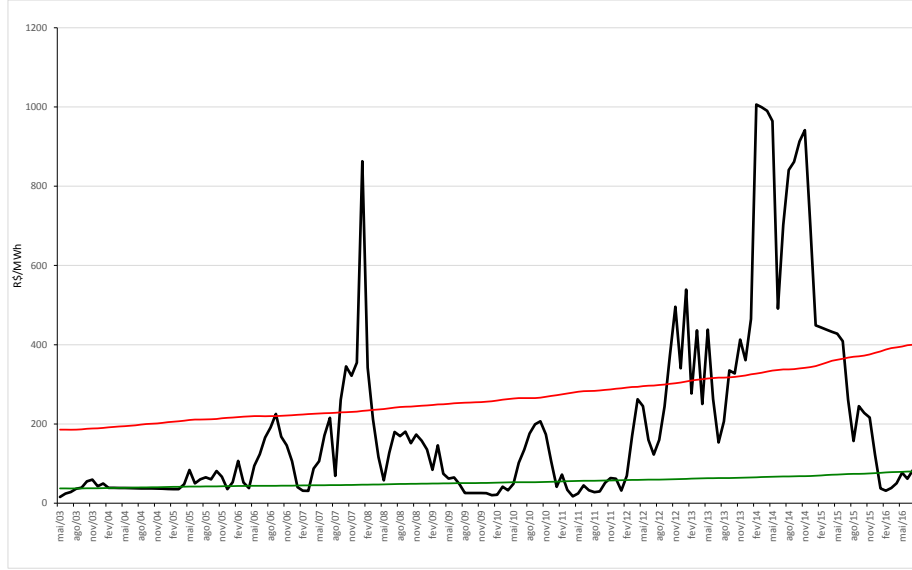


Figure 2: Spot prices and strike prices

$$(p^{floor} - p^{spot}) * C^i \frac{Load}{C^*} \quad (2)$$

The winners of the day ahead auction are the ones selling at the spot market. Note that the financial options preserve production incentives. Low spot prices signal low scarcity and induce hydro generators to save water for future periods. The payments from the put option do not distort this incentive.

4 Long-Term Equilibrium

What can we expect to happen in a decentralized market characterized by the Capacity Markets with Options' Band? Is it reasonable to expect that the market will converge to a technology mix that guarantees a reliable energy production, with low prices and with as much clean energy as possible? While it is not possible to perfectly anticipate how investors would react to such a market design, it is possible to draw some very plausible predictions.

In this proposed market design, thermal producers (or other high-marginal-cost technologies) no longer depend on scarcity periods to profit, their stream of revenues will be determined by the capacity payments. These technologies will be idle most of the time, being paid the option premium and the hedge payments associated to the put options. If spot prices are lower than the put strike prices, the producer earns $(p^{floor} - p^{spot})$, without producing anything. If the spot price is higher than the call strike price, it earns Spot price by producing, but must pay $(p^{spot} - p^{ceiling})$. Given that the strike price of the call option is typically higher than the marginal cost of the producer, these generators face no risks associated to these option bands, but have their gains capped by the upper strike price. This cap is compensated by the constant flow payment of the premium and the hedge payments of the put options.

The intermittent sources will produce even if spot prices are negligible, but financing is guaranteed by the constant flow payment of the strike price of the put option and the premium. Contrary to thermal sources, intermittent sources face risk: if the spot price is higher than the call strike price, they must pay $(p^{spot} - p^{ceiling})$ of hedge payments, but this is likely to happen in a time of scarcity, that is, exactly when the intermittent source does not have energy to produce. Risk Management will be shifted from regulators to private markets, which might be a healthy shift. Nonetheless, to mitigate this problem, our suggestion is that the call strike price should

be as high as possible. Will financing be affected? If one expects a market where there are long periods of very low price (as expected by a typical system dominated by green sources) and only infrequent periods of high price, then the hedge payments to the regulator are infrequent, while hedge payments from the regulator happen for long sequence of periods, guaranteeing a steady flow of payments in addition to the premium.

An essential feature of reliability markets is the complete separation of capacity and energy, implying that the market forces keep the right incentives. To illustrate, imagine a situation of scarcity, this means that prices are high, possibly higher than the call strike price. This is a situation where a benevolent central planner would like to see everybody that can produce, producing. Indeed, when Spot is higher than Strike, every firm contracted must pay $(p^{spot} - p^{ceiling})$ regardless of whether it produced or not. Given that the spot price is very high, any firm that can produce will likely produce. Similarly, when the spot market is smaller than the put strike price, every firm contracted will receive (Strike-Spot), regardless of its production. A benevolent central planner would like to decrease incentives for production in such a scenario, for example in the form of a large reservoir keeping water stored. Given that prices are low, the incentives for production are also kept low, completely independent of the hedge payments.

At first, this might seem like a market that benefits thermal sources in a disproportional way: they benefit from put options in the same way that hydro sources and green energy do, but, given the reliability of their inputs, their risk with call options in periods of extreme prices is lower. Following this argument, thermal sources would be more competitive in the auctions for capacity option bands, implying a market with higher concentration of this technology. This, however, cannot be an equilibrium. If agents anticipate such a movement, they will also anticipate that a market concentrated with thermal sources will imply high spot prices and fewer periods of scarcity. This reduces the risk inherent in the call options and increases the profitability of low-marginal cost producers. So, they will enter. Again, if many of them are expected to enter, spot prices drop significantly, and a Thermal source will find it profitable to enter the market and earn the hedge payments associated to the low prices. The inductive reasoning goes on. What will be the equilibrium? While it is not possible to forecast exactly what the technology mix will turn out to be, we have argued that it will not be a corner solution: an equilibrium requires enough thermal sources to profit from hedge payments when prices are low and enough intermittent sources to profit from the high spot prices induced by thermal sources.

What about the clean energy paradox? Suppose the government decides that the market forces are not inducing the right mix of technologies in the sense that they fail to capture the externalities of the different sources. In other words, suppose that the government decides to subsidize green energy by offering them an advantage in the auctions, for example. As more green sources enter the market, prices are forced down. As they are forced down they decrease it below the put strike price, becoming attractive to thermal sources, which move prices back up, and thus the so-called green energy paradox, where a policy of more green sources decrease prices, making a policy of green sources ever more expensive is not present here.

5 Conclusion

We propose a capacity market that takes into account the challenges of intermittent - solar and wind - and hydro power plants. For this aim, we propose a capacity market with call and put reliability options. The put option brings financial stability for periods of very low prices, which can happen in systems with a significant share of hydro and/or intermittent technologies.

This paper tries to evaluate the design proposed by asking the following questions. First, are the expensive but reliable thermal plants shut out of the market by low cost intermittent/hydro plants? Second, how do the hydro/intermittent plants deal with periods of high prices when the call option is activated but they may be unable to produce energy due to lack of water for example? Third, does the put option induce the entry of hydro/intermittent sources?

Despite not being able to give a definitive answer about the optimal mix of technologies, we argue that the proposed market design gives the correct incentives for a balanced mix of technologies in equilibrium. For example, the entry of many hydro plants would drop the electricity price when water is abundant. However, when water is scarce, the spot price would rise, giving incentives for the entry of thermal plant that operates in peak periods.

References

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