INVESTMENT DYNAMICS AND LONG TERM PRICE TRENDS IN COMPETITIVE ELECTRICITY MARKETS

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Abstract: This paper analyses long term price trends in deregulated electricity markets. A price model using explicit supply and demand states is introduced. A stochastic model for demand growth drives future uncertainty, and investors respond by adding new capacity based on price feedback. Effects of delays in the supply response, through information lag or construction time, on price dynamics are illustrated through simulations. The model is extended to account for physical reliability problem resulting from a lack of generation capacity. It is shown how inappropriate intervention by regulators, through the use of price caps, can result in a critical decrease in the markets reserve margin. *CopyrightÓ2001IFAC*

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1. INTRODUCTION

Our attention is often drawn to competitive power markets in times of crisis, and recently electricity markets have experienced unprecedented levels of price volatility. Each time prices spike, there are those who call for regulatory intervention to protect customers and keep large suppliers from exploiting shortages. Most recently, the power crisis in California resulted in both financial losses for the load serving utilities, and the physical loss of power for some of their customers. This resulted in a public reevaluation of the success of deregulation in lowering the cost of electricity for the consumer, as well as in the more basic objective of keeping the lights on.

The paper addresses the question of price trends in competitive electricity markets, both in terms of economic efficiency and physical reliability. The key to successful deregulation does not lie in the daily operation of the system. Short-term optimality is always easier to achieve in a regulated, centralized industry. The goal of deregulation should be to provide the right incentives for new investment, and the development of innovative technologies. This evolution occurs at a longer time scale, and with its own dynamic constraints (Ilic and Skantze, 2000). In order to successfully transition to a deregulated environment, the regulators must recognize the nature of the decentralized decision process, which governs new investment. This includes modeling the effect of price signals on investment, and understanding the impact of delays in information on price dynamics as well as the physical power balance on the system. Only if these relationships are fully understood, should a regulator attempt to intervene into the marketplace.

Section 2 introduces a long-term price model, driven by a stochastic model for demand growth. In section 3 it is shown how the rate of investment can be modeled as a function of price feedback. Sources of delays in the feedback signal are identified and their impact on price dynamics illustrated through simulations. Section 4 addresses the coupling between price dynamics and market reliability, and Section 5 illustrates how regulatory intervention, through price caps, can lead to reliability problems.

2. A LONG TERM MODEL FOR ELECTRICITY PRICES

The model characterizes spot price as a function of two state variables; L representing the aggregate market demand, and b representing the current state of supply. This model is different from the other stochastic models of energy commodity prices such as the one proposed by Deng (2000). This paper will be focused on the long-term dynamics of the electricity prices. A more detailed discussion of the model presented in this section, which captures short-term deviations in prices, can be found in Skantze, *et al*. (2000a). The demand for electricity is assumed to be inelastic, while the basic shape of the aggregate supply curve is characterized by an exponential function, with a stochastic shift parameter b. The average price in a month m can then be written as,

$$S_m = e^{aL_m - b_m} \tag{1}$$

where a is a fixed parameter characterizing the shape of the bid curve.

1.1 Stochastic Demand Process

Demand for a given month m is modeled a the sum of a deterministic component μ, and a stochastic component δ.

$$L_m = \mu_m^L + \delta_m^L \tag{2}$$

where $\mu_m{}^L$ captures the seasonal behavior of load. The state $\delta_m{}^L$ represents the long-term uncertainty in load, which grows stochastically with a drift κ, and volatility σ.

$$\delta_{m+1}^L - \delta_m^L = \kappa^L + \sigma^L z_m^L \,. \tag{3}$$

3. MODELING INVESTMENT DYNAMICS

Having developed a model for the stochastic growth of demand in the market, one can now address the question of how new generation capacity is added to the system in response to the load growth. It is assumed that the decision process for investing generation assets is decentralized. Each investor makes decisions in order to maximize his own utility, and there is no higher level entity coordinating investment behavior in the market place. For an in depth analysis of investment decisions under uncertainty, see Dixit and Pyndyck (1994). The rate of investment will not be governed by projections of overall demand and supply mismatches, as was the case in the regulated industry. Instead, investors react to price signals from the market in making their decisions. While price signals are inherently linked to the demand and supply levels, this change from a physical to a financial investment signal has profound effects on the dynamics of investment, and ultimately on the physical reliability of the system.

1.2 Backward Looking Investment

In the first model, it is assumed that the investor observes a moving average of the last 12 months of spot prices, S^{ave}. He compares this value to the index, I, of the available technology to invest in. I reflects the marginal cost of running the new unit, as well as the installation cost (Skantze, et al., 2000b). If the average spot price rises above the index value, one starts to observe new investment in the market. The greater the differential between S and I, the higher the rate of investment, this difference is referred to as the investment signal. The parameter G determines the rate of investment in response to an investment signal. G can be thought of as reflecting the availability of capital in the market. Finally negative investment, that is the removal of capacity from the system in response to low prices, is not allowed. The model for new investment is defined as follows. As with the load model, the stochastic component δ is separated from the seasonal component μ,

$$b_m = \mu_m^b + \delta_m^b \,.$$

The stochastic component evolves according to the following dynamic equation,

$$\delta_{m+1}^b - \delta_m^b = \max(0, G(S_m^{ave} - I_m)) + \sigma^b z_m^b \tag{4}$$

where,

$$S_k^{ave} = \frac{1}{12}\sum_{j=1}^{12} S_{k-j} \,.$$

The model is backward looking because the investment decision reflects the previous 12 months of spot prices. In a market where investment decisions are made based on historical spot prices, there is an inherent delay between increased spot price levels and increased investment. Due to this delay, investors will continue to inject capital after spot prices have declined below critical levels. In a market with growing demand, this results in cyclical swings of high and low spot price periods, as investors alternately overshoot and undershoot their optimal investment levels. This effect is lost in standard economic equilibrium models, where it is assumed that suppliers are able to immediately take advantage of price increases. Another critical element in investment dynamics, is the delay between the time that a decision to invest is made, and the time that the new generation plant is actually connected to the power grid. This delay has two components. The first is the time it takes for the plant to be licensed by the regulators. The system operator goes trough an extensive study on the effects of each new plant on the network, and approval can take over a year. Next there is the production and installation time of the actual generator. Put together these delays can block the markets ability to correct for generation deficiencies, further accentuating the cyclical price behavior observed above. This delay is accounted for by introducing the parameter τ in the dynamic equations governing investment,

$$\delta^{b}_{m+1} - \delta^{b}_{m} = \max(0, G(S^{ave}_{m-\tau} - I_{m-\tau})) + \sigma^{b} z^{b}_{m} \qquad (5)$$

The longer the delay, the greater the tendency for extreme price spikes followed by periods of suppressed price levels. The interaction between spot price levels and the investment decision, including the delays, is depicted in Fig.1.

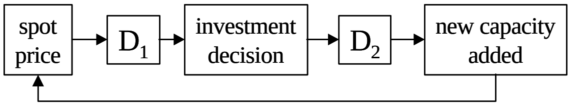

Fig. 1. Interaction between spot price levels and the investment decision.

Fig. 2 shows a simulated comparison of behavior of market behavior without delays, and with a six-month delay period, over a 100-month period. The parameters used in the simulation are provided in Table 1. It should be noted that these simulations are provided to gain a qualitative understanding of market behavior, rather than quantitative predictions.

Table 1 Parameters used in the simulations.

Load	μ^L=12,000	σ^L=100	κ=100
Supply	μ^b=1.2	σ^b=.01	G=.003
other	a=5*10^{-4}	I=150	τ=0,6

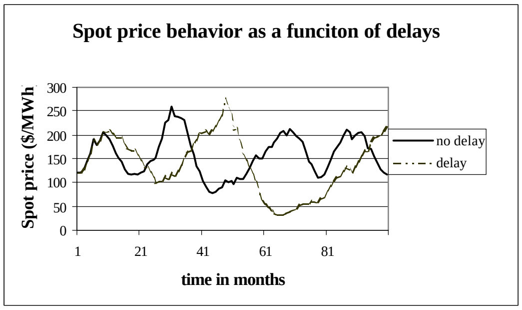

Fig. 2. Simulated comparison of market behaviors without delays, and with a six-month delay period.

1.3 Forward Looking Investment

Two sources of delays in the investment dynamics have been identified. A delay from the price signal to the investment decision and a delay from the investment decision to the installation of the plant. Both of these delays could be negated if investors were able to project future price trends. A long-term price estimator would allow investors to base their decisions on projected future revenues, rather than historical data. This would have a stabilizing effect on the market, and eliminate much of the cyclical price behavior.

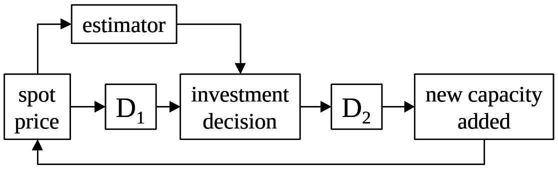

Fig. 3. Interaction between spot price levels and the investment decision with a price estimator.

The challenge in the estimation problem lies in the fact that it requires the user to model the decision process of all other investors. The problem may be tractable in the case where there is sufficient historical data available to estimate the cumulative investment rate in response to market price (the G parameter in our model). However in the early stages of a market, such as the current situation in the United States, one would be forced to arrive at this parameter by deriving likely competitor strategies. This would be a very complex game theoretic problem, where the outcome will depend on how sophisticated market participants are in their decision process, (Visudhiphan and Ilic, 1999; 2000).

The Role of Futures Markets

In the context of forward-looking investment, futures markets play an important role as an information provider. It is questionable whether futures prices truly reflect the expected value of future spot prices, but the prices do reflect information, which is not present in historical spot prices. For instance, power marketers keep a close watch on the permit requests and manufacturing orders for new generators. This gives the marker an estimate of the amount of new generation capacity is likely to be added in a given area in the near future. The information is incorporated in the marketers' futures trading strategy (Skantze and Ilic, 2000). If a region has a current generation shortage, and accordingly high spot prices, but there is an abundance of new turbines in the manufacturing or permitting stages, the futures prices will tend to be depressed. If investors observe the futures market, and if the new generation capacity in progress is accurately reflected in the futures prices, it will prevent over- and under-investment, thus stabilizing the spot price dynamics. There are two critical properties which futures markets must satisfy in order to effectively govern investment dynamics (Hull, 1996; Schwatz, 1997).

- **Liquidity:** The volume traded on futures markets is not necessarily proportional to the total load on the system. Instead it reflects market participants desire to hedge their positions, or to speculate on future spot price levels. In order for the futures price to be a useful signal to investors, it has to be credible. That is, one must be able to buy and sell power in significant volume at or near the price quoted in the exchange. This in turn requires that there exists a large number of participants who actively trade in the market.

- **Duration:** The duration of a market refers to the longest time to maturity of all contracts currently trading in the market. If a market has a duration of 12 months, then a contract which matures April 1, 2002, will start to trade on April 1 2001.To understand the importance of the futures market duration, consider the position of an investor who is contemplating financing a new power plant. The plant is estimated to take one year to be built and permitted. The investor is willing to undertake the project, if he is expected to recover his initial capital investment in five years. To solve the decision problem, the investor must project the cash flow from the plant, and therefore the spot price levels, six years into the future. A futures market with duration of a year or less has a limited value since he expects no cash flow until the plant is finished. A market with a duration of three or five years however, would allow the investor to not only make a market based estimate of future cash flows, but also lock in some of these revenues by selling futures contracts.

The two objectives, liquidity and duration, can be contradictory. By increasing the duration of the market, one increases the number of different contracts traded simultaneously, since each delivery month is a separate contract. This makes it more difficult to find two counter parties willing to trade at the same contract at the same time. Currently, the two main exchanges, NYMEX and CBOT, trade contracts up to fifteen months prior to delivery. This is not a sufficient time horizon for an investor seeking to value or hedge a new plant. At the same time, the exchanges are experiencing a lack of liquidity even for near term contracts.

This study will not be attempted to simulate the impact of futures markets here, since it would require us to make unfounded assumptions about traders' strategies. There are a few points, which need to be studied carefully as more data becomes available from the futures exchanges.

1. To which extent do futures prices contain information, which cannot be derived from historical spot prices?
2. Do investors depend heavily on futures price signals in making their investment decisions, or do they tend to wait until price changes appear in the spot markets?
3. Does the presence of a liquid futures market have a stabilizing effect on the spot market, eliminating periods of extreme over and under capacity?

4. A DYNAMIC NOTION OF RELIABILITY

When capital investment fails to keep up with load growth, there are two measurable effects in the market. The first is an increase in the spot price, as discussed in the previous section. The second effect is a reduction in the available generation reserve R, defined as the amount of unused generation available in the market as a fraction of the total load,

$$R_k = \frac{C_k - L_k}{L_k}, \qquad (6)$$

where C is the total capacity of all available generation assets. In a market with little or no demand elasticity, retaining a generation reserve is the only means of avoiding customer curtailments or blackouts as a result of unexpected load spikes or generation outages. The Federal Energy Regulatory Committee (FERC), sets guidelines for how much generation reserve each region should retain. It is the job of the independent system operators (ISOs) to enforce these reserve requirements. The system operator will do this by contracting generators to be in a stand by mode. The compensation paid to these generators is determined through auctions similar to the electricity spot market. The problem is that if there is not enough total generation capacity in the market, the ISO will be unable to purchase reserve generation at any price. Furthermore the ISO is not allowed to build or own generation assets. The system operator is therefore unable to guarantee that the system meets the reserve margin. The reliability of the system can only be ensured by the addition of new generators, and investment into these plants is determined by for profit market participants. The reliability of competitive electricity markets is therefore directly coupled to the spot market price dynamics.

To illustrate the link between reliability and spot price dynamics, the model is further amended. Starting with a total capacity equal to the initial load, plus a reserve margin X,

$$C_0 = (1 + X)L_0 . \qquad (7)$$

Every time there is new investment in generation, reflected in the supply state δ^b, there is an associated increase in the total available capacity C,

$$C_k = C_0 + \frac{1}{a}\left(\delta_k^b - \delta_0^b\right), \qquad (8)$$

recognizing that a 100MW increase in L is perfectly offset by a (1/a)*100MW increase in b.

5. EFFECTS OF GOVERNMENT POLICY

In periods of high price levels, consumer advocates can put pressure on the government to impose price caps on the market. The argument is that suppliers are taking advantage of the generation shortage in order to drive up prices, either by withholding their generation or bidding it in at inflated price levels. The issue of ‘fair’ pricing of electricity will not be addressed here. Instead we will try to answer the question of whether price caps are an effective means of reducing price levels in the long term. To do this the market is simulated under two conditions. The first is without a price cap, as shown above. In the second case, a price cap is introduced, leading to the condition,

$$S_k = \min(\text{cap}, e^{aL_k - b_k}) \qquad (9)$$

where ‘cap’ is the \$/MWh price cap imposed by the regulator.

From the simulation it is clear that while the cap eliminates periods of high prices, it also raises price levels during the low price cycles. This result is easy to understand if one goes back and examines the signal which drives new investment,

$$S_k^{ave} - I\,. \qquad (10)$$

By reducing price levels when supply is scarce, the regulator reduces the rate of new investment into generation. As a result prices drop of at a slower rate, causing higher future spot prices. In the case described, the average power price is higher in the case where price caps are imposed.

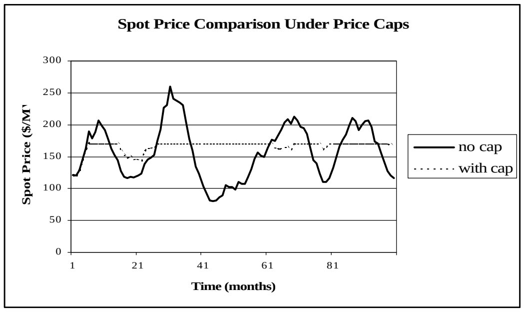

Fig. 4. Spot price dynamics with a price cap and without a price cap.

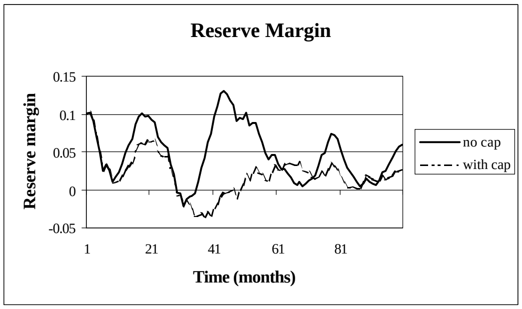

Fig. 5. Dynamics of reserve margin when there is a price cap and no price cap.

5.1 Comments on Simulation Results

The simulation demonstrates that reserve market levels tend to be lower in cases where a price cap is imposed by the regulators. When the price cap is near the critical investment level I, one starts to observe negative reserve levels. In these instances the system operator must order the curtailment of some customers, possibly through rolling blackouts, in order to prevent the collapse of the entire system. The simulation illustrates a trap, which the regulator must avoid. By imposing price caps, the regulator succeeds in eliminating price spikes from the market. At the same time, the investment rate starts to drop off, thereby increasing price levels on the low end of the price cycle. The net effect is a flattening out of the price trend, which may actually raise the average price of electricity of a multiyear period. At this point its is tempting for the regulator to force down the average price by further reducing the level of the price cap. ***This is a dangerous move, because it decouples the spot price level from the economic reality of supply and demand.*** The scarcity of supply is not translated into high prices, and therefore the economic signal to investors to build new plants is blocked. Eventually the physics will catch up with the economics, as the available generation will no longer be able to meet demand, resulting in curtailments. The critical price level ($S^{critical}$) at which point investment will no longer keep up with demand growth is given by,

$$G(S^{critical} - I) = a\kappa\,. \qquad (11)$$

If the price cap is set below $S^{critical}$, then investment cannot keep up with load growth, and the system is invariably headed towards blackouts.

The implications of the results in this paper must not be interpreted as rejecting all forms of regulatory intervention in general, and price caps in particular. There may be instances where it is necessary for the government to set temporary limits to the price in a market to prohibit suppliers from exploiting shortages. What the model illustrates is that the regulator must be very careful in setting these limits. Price caps must be set higher rather then lower, to ensure that the economic feedback is not blocked, and that market forces are allowed to bring the system back to stable price levels. Once price caps have been put in place at a too low level, they become increasingly difficult to remove, as the generation shortage worsens.

6. CONCLUSION

The paper addresses the interplay between spot price levels and investment into new generation capacity in competitive electricity markets. The problem was addressed from the viewpoint of economic efficiency as well as the physical reliability of the system. Special emphasis was placed on the dynamic properties of the investment process. It was shown that delays caused by backward looking investment, as well as licensing and construction time of the asset, leads to periods of over and under investment. This in turn leads to a cyclical long-term price behavior, driven by a stochastic growth in demand, which does not settle to an equilibrium level. The structure of the problem indicates that the presence of liquid futures markets could reduce the information delay, and help stabilize the system. This assumes however that futures markets contain information, which is not reflected in historical spot prices, or that is otherwise part of the public knowledge. Further research into the effect of futures markets on information flow could involve simulations of bottom up, agent based models, to determine the extent to which locally held information is reflected in the futures price. While it may not be possible to accurately calibrate such models to the market, they would provide important qualitative insights into optimal decision rules for investors, as well as intelligent market designs for the deregulated electricity industry.

In the final part of the paper, the dynamics of spot price and new investment was linked to the physical reliability of the system. Periods of under-investment not only lead to higher price levels, but also reduce the reserve margin of available generation, and could lead to generation deficiency and blackouts. The first reaction of regulators to periods of high prices is often to try to force price levels back down through the use of price caps. Price caps however, inhibit the economic feedback, which would allow the market to readjust itself. Imposing the caps will reduce the rate of new investment, leading to a slower recovery from the price hike. If the regulator continues to force the issue by reducing the cap levels, the lack of new investment will eventually lead to an erosion of the reserve margin, leading to load curtailments and blackouts on the system. The results presented in this paper indicate that regulators have to be cautious in the use of price caps. They must respect the unique characteristics of electricity as a commodity; non-storability, inelasticity of demand, and a highly constrained transmission system. These characteristics lead to an uncommonly strong link between market price signals, and physical stability. Any attempt to block the true economic signals from the market could therefore prove disastrous.

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