SPOT PRICE SIMULATION AND VOLATILITY ANALYSIS IN THE FUTURE IBERIAN ELECTRICITY MARKET

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Abstract – Price volatility is a major issue in liberalized electricity markets as far as risk management is concerned. In this paper we evaluate the impact of the Portuguese and Spanish electricity markets integration on the day-ahead market price volatility. For that purpose we develop an adaptive conjectural variations model which is implemented in GAMS language. We estimate the degree of competition in the Spanish pool using an iterative secant method applied to a conjectural variations oligopoly model. Using the estimate obtained, we simulate the Portuguese and Spanish markets in autarky and the integrated market, known as the Iberian Electricity Market (IBELM). We present conclusions on the impact of the IBELM on prices and volatilities from the Portuguese and Spanish markets point of view.

Keywords: Price volatility, Risk management, Conjectural variations, Iberian Electricity Market, GAMS simulation

1 INTRODUCTION

In the past, power electricity systems were run by vertically integrated, typically state owned, monopolistic companies, comprising the generation, transmission, distribution and supply activities. Major uncertainties were passed through the final consumers by a tariff that included all operating and investment costs. This structure has been criticized on different grounds and reforms have taken place in many countries around the world.

In liberalised electricity markets power producers and customers face a market risk with prices that can be very volatile, being price volatility defined as a measure of the fluctuation in prices observed over a period of time.

Unlike other commodities, electricity lacks of relevant storage mechanisms (with the exception of pumped storage hydro plants) which implies the need for a continuous balancing of demand and supply. On the other hand, in the short run, demand is very rigid in respect to price.

As a result, electricity prices can change drastically compared to the prices of other commodities or equities, leading to an electricity price volatility consistently and significantly higher than other products.

A large number of parameters determine price volatility such as fuel prices, foreign exchange rates, variation in hydroelectric production, generation availability, demand variability and network congestions.

Different approaches for measuring wholesale electricity market price volatility have been proposed by several authors. Alvarado and Rajamaran [1] modelled electricity prices assuming a random walk process with a strong mean reversion, using a frequency domain analysis to separate the cyclic component of price. Benini et al. [2] analysed the spot market price volatility in Spain, California, UK and PJM markets using the concept of the expected price. This time domain approach was used to decompose the cyclic and random components of electricity prices.

Other studies were developed to incorporate volatility and estimate wholesale electricity prices [3,4], as well as quantifying risk exposure of generation companies (GENCOs) applying financial methods like Value-at-Risk (VAR) [5].

For some authors electricity spot market price volatility can be mitigated by using discriminatory price auctions (DPA) instead of uniform price auctions (UPA) [6]. However, this approach is criticized on the grounds that DPA produce prices that converge to the level of the highest prices observed with the UPA [7].

The new world of uncertainty requires risk management tools such as derivative securities (forwards, futures and options) and bilateral trading [8].

In this regard, it is of great interest to evaluate the impact of electricity markets integration, such as the upcoming Iberian Electricity Market (IBELM), starting operation foreseen until June 2005, which aims the full liberalisation and integration of the Portuguese and Spanish electricity markets.

Bearing in mind that the impact of such an integration is a major concern for the Iberian power producers and consumers, we answer the following question: What is the impact of the Portuguese and Spanish electricity markets integration on the day-ahead pool prices volatility?

For that purpose we carried out a study based on a 744 hourly demand data for the month of October 2002. A pre-processing of the input data was needed for the Spanish hydro generation, since it was available on a daily basis only. Therefore, a short-term hydrothermal model [9] was used to divide the daily hydro energy reported by REE [10] into equivalent hourly data. Portuguese power data was given by the Portuguese system operator REN.

A conjectural variations model was used to simulate the Portuguese and Spanish price and volatility in comparison to the simulated IBELM outcome. The competitive paradigm among firms is modelled using the proposed concept of adaptive conjectural variation.

2 ADAPTIVE CONJECTURAL VARIATION

Conjectural variations models became popular in electricity markets simulations because of their ability to forecast prices in line to real data.

In this study we propose an original contribution by adjusting a conjectural variations model to observed data in order to access the degree of competition in each simulated period.

The model comprises supply, demand, market equilibrium and adaptive conjectural variations.

From the supply side, GENCOs bids are established by their optimal strategy assuming a conjectural variations model. Demand is fitted to observed data from the Spanish pool - OMEL [11] using a sigmoid type function. Market equilibrium is simulated using a mixed complementary problem formulation. The concept of adaptive conjectural variation is introduced to measure the degree of competition observed in each hour of OMEL. This level of competition is then assumed for the simulations of the Portuguese, Spanish and IBELM markets for the same hours.

2.1 Supply

The supply of electricity is done by GENCOs that hold different generation portfolio technologies. Each firm's cost is given as a function of its output, according to equation (1):

$$C_i(q_i) = a_i + b_i\, q_i + c_i\, q_i^2 \qquad (1)$$

where q_i is the output of GENCO i and a_i, b_i and c_i are non-negative coefficients.

The marginal cost of generation is given by (2) as the derivative of (1).

$$C_i'(q_i) = b_i + 2\, c_i\, q_i \qquad (2)$$

In our model the coefficients b_i and c_i are estimated using a least squares minimization (3).

$$\min_{(b_i, c_i)} \sum_{j=1}^{m} \int_{x_{j-1}}^{x_j} \left[b_i + 2\, c_i\, x - y_j \right]^2 dx \qquad (3)$$

where x is the installed capacity by technology and y the corresponding variable costs.

2.2 Demand

The inverse demand curve is fitted to the observed OMEL data using a proposed sigmoid type function with parameters k_0, k_1 and k_2, given by expression (4):

$$P(Q) = \frac{k_0}{1 + k_1\, e^{Q - k_2}} \qquad (4)$$

The parameters are computed so that the highest valuation point and equilibrium point are exactly matched, which corresponds to points A: (0, P_{max}) and B: (Q^*, P^*) in Figure 1.

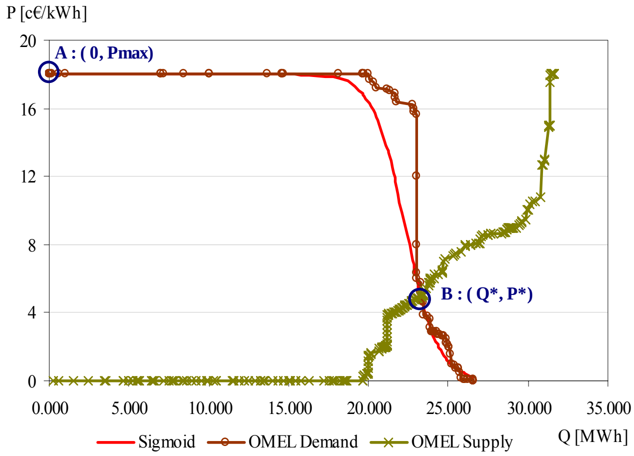

Figure 1: Sigmoid fitting of the inverse demand .

The demand that corresponds to (4) is given by solving the equation in order to Q.

$$Q(P) = k_2 + \ln\left(\frac{k_0 - P}{k_1\, P} \right) \qquad (5)$$

The demand of the Portuguese and Spanish systems in autarky, as well as integrated in the IBELM, is computed by extrapolation of (5).

This consideration leads to the following expression for market m (Portugal, Spain and IBELM):

$$Q_m(P) = \beta_m\, Q(P) = \beta_m \left[k_2 + \ln\left(\frac{k_0 - P}{k_1\, P} \right) \right] \qquad (6)$$

where β_m is the scale factor given by the relationship between the demand of market m and OMEL.

The inverse demand function of each market is then given by:

$$P_m(Q) = \frac{k_0}{1 + k_1\, e^{\frac{Q}{\beta_m} - k_2}} \qquad (7)$$

2.3 Market equilibrium

The market equilibrium is reached by the solution of the profit maximization problem of the firms competing in an oligopoly market, with cost function defined by (1) and facing an exogenous inverse demand curve given by (7). This problem is defined for firm i in (8):

$$\max_{q_i} \quad \pi_i(q_i) = P(Q)\, q_i - C_i(q_i) \qquad (8)$$
$$\text{s.t.} \quad 0 \le q_i \le K_i$$

where

q_i : power generation of firm i
π_i : profit of firm i
Q : demand
$P(Q)$: inverse demand function
$C_i(q_i)$: generation costs fo firm i
K_i : total installed capacity of firm i

The market clearing condition should also be met:

$$\sum_i q_i = Q \quad (9)$$

The solution of (8) and (9) is reached using game theory for the modelling of the strategic interaction among all the firms.

The necessary optimality conditions (also sufficient for this problem) of Karush-Kuhn-Tucker (KKT) for firm i are given by:

KKT1:
$$\begin{aligned} & q_i \geq 0 \\ & K_i - q_i \geq 0 \end{aligned} \quad (10)$$
$\exists_{\lambda_{1i},\lambda_{2i}\geq 0}$:

KKT2:
$$\begin{aligned} & \lambda_{1i}\ q_i = 0 \\ & \lambda_{2i}\left(K_i - q_i\right) = 0 \end{aligned} \quad (11)$$

KKT3:
$$P(Q) + \frac{dP}{dq_i} q_i - C_i'(q_i) + \lambda_{1i} - \lambda_{2i} = 0 \quad (12)$$

where $\frac{dP}{dq_i}$ represents the effect of the firm i output on the market clearing price (P). This effect can be decomposed into direct and indirect contributions, expressed by the chain rule of derivative:

$$\frac{dP}{dq_i} = \frac{\partial P}{\partial Q}\frac{\partial Q}{\partial q_i} + \frac{\partial P}{\partial Q}\frac{\partial Q}{\partial q_{-i}}\frac{\partial q_{-i}}{\partial q_i} = \frac{\partial P}{\partial Q}(1+\theta) \quad (13)$$

where $q_{-i} = \sum_{j\neq i} q_j$ and $\theta = \sum_{j\neq i}\frac{\partial q_j}{\partial q_i}$.

The parameter θ so defined represents the conjecture that firm i does about how its rivals change their quantities is response to changes in its own quantity. Therefore θ is called the conjectural variations parameter.

The value of θ represents the degree of competition in the market. In fact, θ=-1 models the perfect competition paradigm whereas θ=0 represents the Cournot competitive outcome. Collusive arrangements among firms can be modelled by positive values of θ.

2.4 Finding the adaptive conjectural variation

The conjectural variations model solves the market equilibrium for the supply and demand conditions with the competitive paradigm assumed for the firms represented by parameter θ.

Therefore, there exists a different market price for each value of θ, assuming the same supply and demand conditions, which represents the different possible degrees of competition among firms, ranging from prefect competition (θ=-1) to collusion (θ positive).

The relationship between price and the conjectural variation parameter led to the concept of adaptive conjectural variation as the value of the degree of competition compatible with a given observed price.

This approach is implemented by an iterative process based on the secant method. From initial values for θ we simulate the correspondent price. A new value for θ is then computed by the secant method. This process is repeated until the deviation of the observed price (P^*) and the simulated price is lower than an arbitrarily small constant (δ). The flow chart of Figure 2 shows the iterative process described.

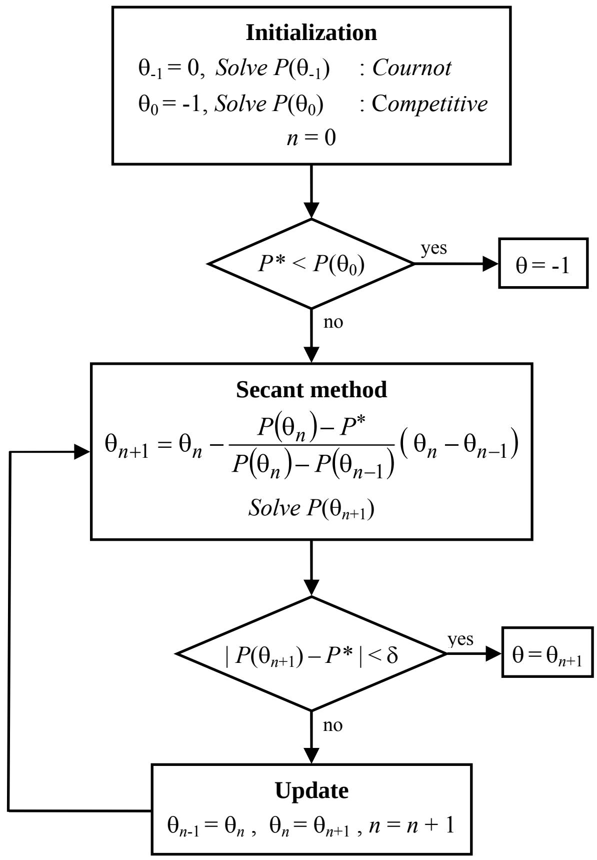

Figure 2: Finding the adaptive conjectural variation parameter using the secant method.

Is should be noted that a value of -1 is assigned to θ when P^* is lower than the simulated competitive price, meaning that the market price corresponds to a possible short-run undercutting bidding situation.

3 SPOT PRICE SIMULATION

The model of adaptive conjectural variations was implemented in GAMS language for the simulation of the 744 hours of October 2002.

The observed and simulated prices of the Spanish pool are shown in Figure 3 where the adaptive conjectural variation θ is also displayed. Competitive behaviour close to perfect competition is observed in off-peak hours whereas the use of market power is evident in peak hours.

Using the estimate hourly value of θ we simulate the market price for Portugal, Spain and IBELM, which is shown if Figure 4.

From this figure it can be observed that Portuguese prices are always significantly higher than the IBELM prices, specially in peak hours. On the other hand, Spanish prices are always close to the IBELM prices, being lower in off-peak hours and higher in peak hours. This fact can be explained by the differences in competitive behaviour among periods. In off-peak hours the installed capacity in significantly higher than the demand and no firm has enough market power.

Therefore, the perfect competition paradigm applies, and prices in the integrated market (IBELM) are in between the prices of the two separate markets (higher in Portugal and lower in Spain) as shown in [12]. On peak hours, when some firms produce at maximum capacity, there is increased market power of the other firms on the residual demand. In this case, integration has a mitigation impact on market power, leading to a price in the integrated market lower than the price that would occur in each of the two separated markets, as described in [13].

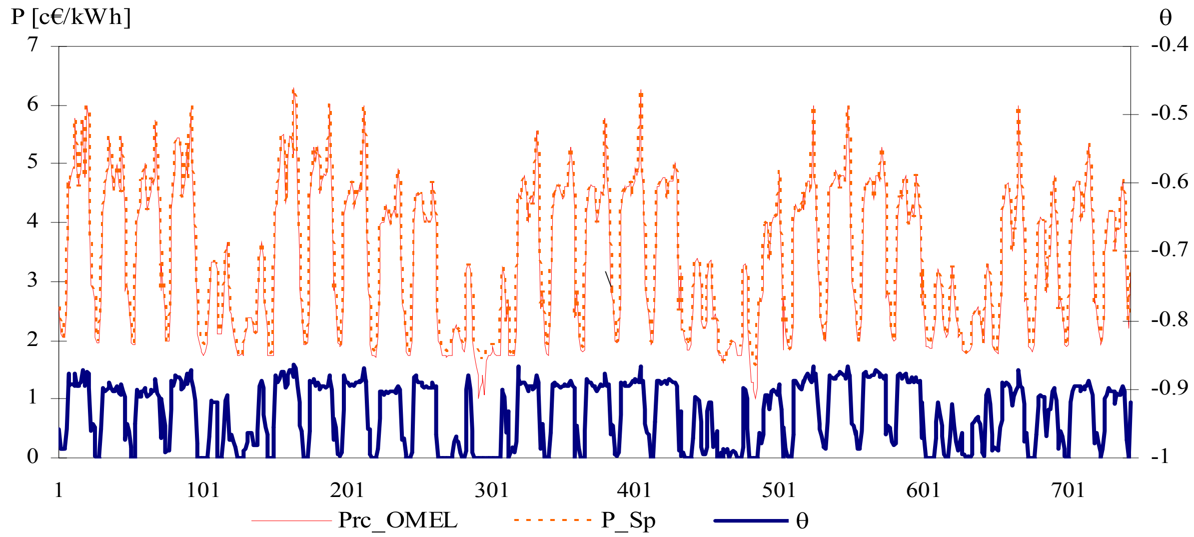

Figure 3: Observed OMEL prices (Prc_OMEL) vs simulated Spanish (P_Sp) prices and estimate conjectural variation (θ).

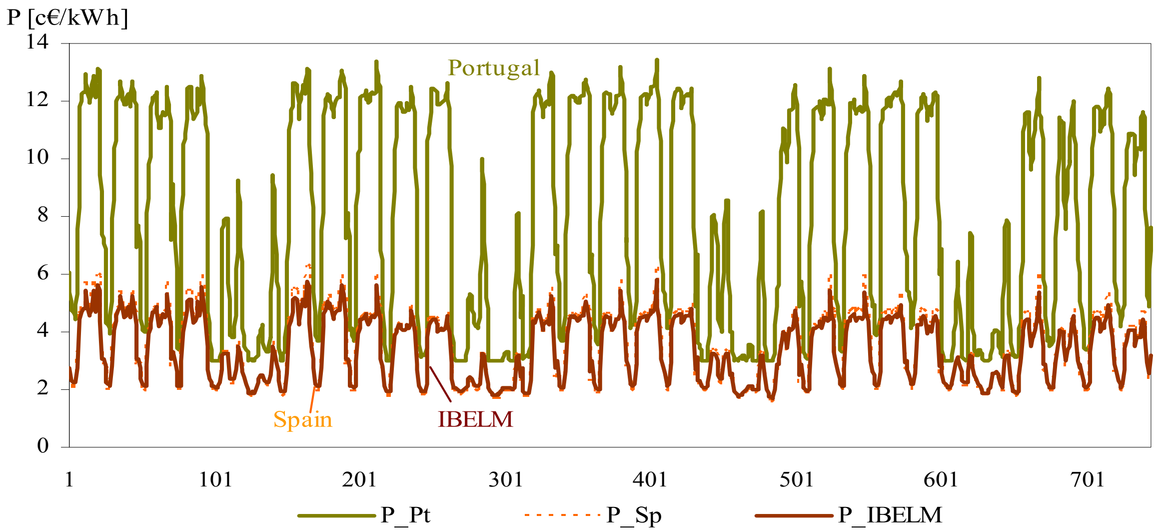

Figure 4: Simulated prices for Portugal (P_Pt), Spain (P_Sp) and IBELM (P_IBELM).

4 VOLATILITY ANALYSIS

Price volatility is a measure of the variability of price in a given period of time. In order to evaluate the price volatility we compute hourly price changes (u_t), given by (14).

$$u_t = \Delta P_t = P_t - P_{t-1} \quad (14)$$

Price volatility is then given by the estimate of the standard deviation of u. The volatility is computed as in (15).

$$s = \sqrt{\frac{\sum_{t=1}^{N}(u_t - \bar{u})^2}{N-1}} \quad (15)$$

Using the simulated prices for Portugal, Spain and IBELM, displayed in Figure 4, we compute the price volatility for each market according to expression (15).

Portugal	Spain	IBELM
1.432	0.533	0.437

Table 1: Price volatility for Portugal, Spain and IBELM based on simulated October 2002 prices [c€/kWh].

The results of price volatility shown in Table 1 present evidence that the integration of the Portuguese and the Spanish electricity markets into the IBELM will have a stabilization effect on prices, since IBELM price volatility is lower than the volatility of each market operating separately.

In order to calculate the price volatility trend over the month we define a 24 hour rolling window in which we apply the volatility expression (15), defining this way the one-day price volatility, given by expression (16).

$$s_{1day_j} = \sqrt{\frac{\sum_{t=j}^{23+j}(u_t - \bar{u})^2}{23}} \quad (16)$$

The one-day price volatility for Portugal, Spain and IBELM is shown in Figure 5.

The results displayed in Figure 5 show that the IBELM one-day price volatility is always lower than the price volatility of the Portuguese and Spanish markets operating separately. It can also be noted that weekdays have higher volatility than weekends.

The results can best be understood if we look into the price simulations presented in the previous section, as shown in Figure 4.

From the analysis of Figure 4 it seems quite obvious that price volatility of the Portuguese market is much higher that the price volatility of the Spanish and IBELM markets.

For the Spanish market it is observed that prices change in a wider range than the prices in IBELM, being lower in off-peak hours and higher in peak hours.

As a result, Spanish volatility is consistently higher than IBELM volatility, as displayed in Table 1 and in Figure 5.

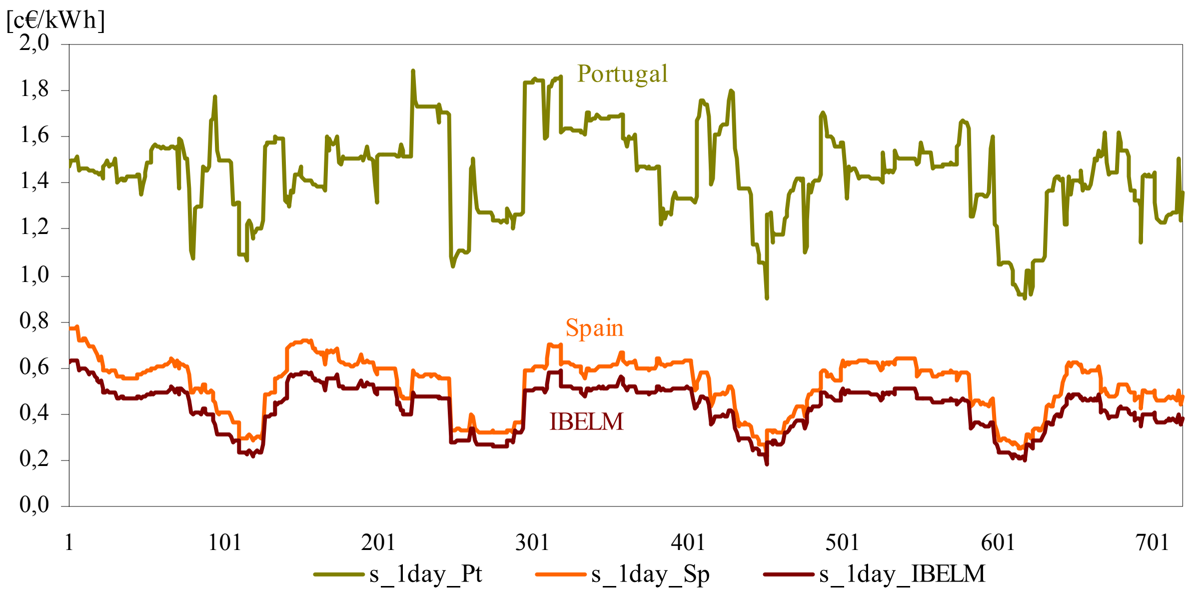

Figure 5: One day rolling volatility (s_1day) for Portugal, Spain and IBELM.

5 CONCLUSIONS

This paper shows the impact on price volatility of the Portuguese and Spanish forthcoming market integration foreseen for June 2005.

Using historic data from OMEL, we access this impact using a proposed model of adaptive conjectural variations to estimate the degree of competition presented in the Spanish pool. The results achieved for this estimate show that the Spanish market is quite competitive in off-peak hours, with prices very close to short-run marginal costs, characterized by values of the conjectural variation parameter close to the perfect competition paradigm. In peak hours, our simulations show evidence of increased market power due to the lack of installed capacity of some competitors.

The degree of competition estimate for the Spanish market was used to simulate the autarky market prices of Portugal and Spain, and the integrated IBELM market.

As a result we conclude that autarky Portuguese prices are always higher than the autarky Spanish prices and the integrated IBELM prices. This is due to the high market concentration in Portugal and generation technology portfolio of Portuguese GENCOs. Therefore, the integration with the Spanish market promotes price reductions for Portugal since it mitigates market power and induces the use of more efficient technologies. Moreover, Portuguese price volatility is also lowered with the IBELM creation, once price would vary in a much narrow range.

On the other hand, autarky prices for Spain change in a wider range in comparison to IBELM, being lower in off-peak hours and higher in peak hours. This is because off-peak hours are close to competitive and the integrated price would be in between the two separate markets. In peak hours the effect of market power reduction is enhanced and IBELM prices are lower. Therefore the market integration would promote a reduction on the Spanish price volatility.

In conclusion, we found strong evidence that IBELM will promote price stability both from the Portuguese and Spanish markets point of view, leading to a less risky market for Iberian power producers and consumers.

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