Modelling Dynamic Interactions and Adaptive Behavior in Balancing Mechanism Offers

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Abstract- **In competitive, bilateral markets, repeated interaction amongst power plants with the same economic characteristics would be expected to result in convergence of their offer prices. If they do not, it raises interesting issues related to the sustainability of heterogeneous competitive strategies. In this paper, we analyze the offer prices submitted to the UK Balancing Mechanism in 2008 by four coal-fired power stations, separately owned (by British Energy, Electricité de France, E.On and Drax), approximately of the same age, size and efficiency, all LCPD compliant, and located in the same congestion zone.**

We find evidence of offer price dispersion and heterogeneous offer strategies despite the repetitive and transparent nature of the market. First, differences emerge across companies concerning both the speed of mean reversion, the volatility persistence, and the frequency and intensity of spikes. Second, while Drax, BE and E.On tie their offers to coal and gas prices, BE offers track the APX day-ahead price index quite closely. Finally, vector autoregressive (VAR) and vector error-correction (VEC) model estimates show that offer prices are co-integrated with coal prices, and that EdF acts as the leader in peak-load periods.

I. Introduction

The balancing mechanism (BM) plays a key role in liberalised power markets, as it provides both the real-time operations to ensure security of supply and price signals for investment in new capacity. Indeed, to the extent that investment decisions are based, inter alia, upon forward prices, these in turn are closely linked to the properties of the stochastic process driving the real time (BM) prices. In the Bessembinder and Lemmon (2002) model, risk-averse generating companies (gencos) and distribution companies are faced with uncertain real-time demand until the forward market clears, and the BM is assumed perfectly competitive. Siddiqui (2003) extends the Bessembinder-Lemmon model by including ancillary services. Glachant and Saguan (2007) distinguish between flexible and inflexible generators and explore the consequences of various imbalance penalty schemes. In this family of models, perfect competition implies that BM offer prices mirror the underlying marginal costs. Moreover, participation in the BM is only driven by price risk: the most risk-averse players sell most of their capacity via forward contracts.

However, the BM efficiency is diminished if gencos exercise market power or if they can set up sophisticated arbitrage strategies between the BM and forward markets.

Furthermore, volumetric risk related to plant inflexibilities can be as important as price risk in driving their trading behaviours. In such cases, offer prices depart from fundamentals, and greater uncertainty ensues; strategies can deviate from competitive behaviour in various ways, giving rise to persistent patterns of price dispersion. For instance, in supply function equilibrium models, differences in the slopes of the cost functions (i.e. differences between portfolios) entail different offer prices (see Sioshansi and Oren 2007 and Hortaçsu and Puller 2008). Sanchez, Bunn, Centeno and Barquin (2009) use an agent-based methodology to allow for learning and risk aversion in a supply function competition model, and find that large players prefer to exercise market power in the real-time market, while smaller companies prefer to contract forward.

It is the aim of this paper to test the empirical relevance of further potential sources of price dispersion and heterogeneity in offer strategies, such as imbalance risk, vertical integration, and leader-follower relationships. We do so by analyzing offer prices submitted in the UK Balancing Mechanism by four coal-fired plants, run by British Energy, Drax, Electricité de France and Eon, all with approximately the same efficiency, size and age, all LCPD compliant and located in the same congestion zone. In particular, we assess the validity of five hypotheses.

Out first hypotheses share the insight that imbalance risk and vertical integration are key determinants of price differentials. First, non-vertically-integrated gencos are expected to ask lower offer prices. The reason is that for non-integrated gencos, arbitrage between BM and forward markets may be the main source of profits. Green and McDaniel (1999) showed that for a low-cost, perfectly competitive genco endowed with one unit of power generating capacity, it may be optimal to set forward offer prices above marginal costs but low enough as to be accepted, so that they are able to buy their capacity back in the BM for prices below marginal costs.[1]

Second, companies whose portfolios include plants with high start-up costs, such as nuclear plants, are expected to ask higher offer prices on some of their more flexible plant. Indeed, if a non-flexible plant scheduled in the day-ahead market has some probability to fail, a genco can mitigate this risk by offering additional capacity in the BM.

We also test the conventional view of real-time offer prices being closer to marginal costs for gencos with larger forward positions, in the spirit of Allaz (1992) and Allaz and Vila (1993), since the role of imbalance risk could undermine it.[2]

The remaining hypotheses are about the offer price dynamics over various time horizons. Concerning the intraday dynamics, a further hypothesis is that the offer prices submitted by larger gencos should display a higher intraday correlation with the forward price. Hortaçsu and Puller (2008) suggest that the bidding capabilities of energy companies may be characterized by economies of scale. Tracking the forward price closely involves a high degree of human asset specificity, and smaller companies may be unable to afford the associated transaction costs. Updating the offer prices several times across the day involves using more and better information, with uncertainty-reducing effects.

Further, gencos who control a large share of power capacity or imports are expected to hold a leadership position. For instance, Bunn and Zachmann (2006) have shown that on peak-load times, the dominant French genco acts strategically by selling electricity to the UK through the Anglo-French Interconnector, even though prices in France are higher. Because this behaviour affects the market equilibrium to a considerable extent, it may be optimal for the other gencos to play the role of the followers. Leader-follower relationships may be particularly relevant as gencos seek to adjust to shocks that drive the market away from its long-term equilibrium.

Finally, we expect to find a long-term relationship between offer prices and marginal generation costs even if the market is not perfectly competitive. After all, any closed-form solution of a strategic interaction model would yield offer prices as functions of the underlying cost parameters.

The plan of the paper is as follows. After describing the UK Balancing Market in Section II, we offer an overview of the results in Section III, based on the estimates of autoregressive time series models with conditional heteroskedasticity and of vector error correction models. Section IV concludes.

II. The UK Balancing Mechanism

Under the British Electricity Trading and Transmission Arrangements (BETTA), introduced on April 1st, 2005, the UK Balancing Market (BM henceforth) is run by National Grid (the transmission system operator) with the goal of maintaining the security of supply by procuring commercial services from generators and suppliers. Trading takes place in half-hourly settlement periods for each day of the year. A generating BM unit will typically be a single generating set in a power station, or the aggregation of smaller sets. On the demand side, a BM unit might be a single large customer or a collection of smaller customers. It is a requirement that the volumes of electricity traded in the forward (bilateral and APX) markets be notified to the system operator by means of Initial Physical Notifications (IPNs) – by 11 a.m. of the day before delivery – and Final Physical Notifications (FPNs) - by "gate closure", that is, not later than 1 hour before actual delivery. IPNs and FPNs take the form of minute-by-minute profiles of the expected power generation or consumption of the relevant unit across each settlement period.

In addition, participants to the BM submit offers and bids taking the form of price-volume pairs. An offer indicates the willingness to be paid in order to increase the amount of power generated or to decrease the demand. Conversely, bids are used by the system operator if the amount of electricity on the system is to be reduced. By means of a bid, a generating unit is able to pay National Grid to reduce generation (whilst still receiving full forward contract revenue for its FPN), and a demand unit may be able to increase its consumption.[3] The

[1] Federico and Rahman (2003) used the same auction-theoretic framework as Green and McDaniel (1999) but take the forward market outcomes as given, and compare the polar cases of perfect competition and monopoly from the social welfare viewpoint. The possibility that gencos may use the BM strategically is not explored.

[2] See also Niu, Baldick and Zhu (2005).

[3] If the system operator subsequently decides that the initial decision to accept an offer (bid) was incorrect, it must accept a bid (offer) from the same unit or from a different unit if this is economically more convenient and/or physically suitable. This means that for every offer (bid), there is a complementary "undo" bid (offer).

system operator may accept all or part of any offer or bid at any time after gate closure until real time.[4]

Generators and suppliers who deviate from the notified FPNs are charged by the system operator for these imbalances. Participants whose imbalance is a net shortfall (i.e. generators who deliver less than they are contracted to deliver, or suppliers who consume more than contracted) are charged the System Buy Price (SBP). Participants whose imbalance is a net spill are paid the System Sell Price (SSP). The imbalance prices for a settlement period are computed as the volume-weighted averages of the accepted offers (for the SBP) and bids (for the SSP) related to that period. Under normal circumstances, the SBP exceeds the SSP, sometimes considerably. The spread between them is designed to encourage participants to balance their physical positions accurately.

III. Empirical evidence

For the purposes of our study, we have collected individual offers submitted into the UK Balancing Market, concerning four coal-fired power stations operated by British Energy (BE), E.On, Drax, and Electricité de France (EdF).[5] We focus on coal-fired plants of approximately the same age, size and efficiency, all LCPD compliant. In case of congestion in the transmission lines, these power stations fall in the same zone. While the plants are very similar, they are run by companies with different portfolios and different degrees of vertical integration. In particular, Drax as a company is simply a very large coal-fired power station. EdF and E.On are also active in the retail segment. EdF is also the dominant French power generating company, who imports and exports power through the Anglo-French Interconnector. BE's portfolio includes nuclear power stations.

For each plant, the sample includes 48 half-hourly observations for each day between 1 January 2008 and 31 December 2008, totalling 262 data points (weekends are excluded). The offer price of plant *i* (period *h*, day *t*) is defined here as the lowest offer price among those submitted by that plant in that market session. This corresponds, in a sense, to the intercept of a supply function.

In this summary, we present the main statistical findings concerning the time series of offer prices for all of the 48 half-hours are presented below, as well as a subset of time series of offer prices in 4 half-hourly periods (10, 13, 27, 35), identified as representative by means of a k-clustering method.[6]

1. Offer prices differ across companies in mean and variance. We have compared the average 2008 plant-level offer prices across companies in selected settlement periods, by means of two-sample t-tests with unequal variances. The tests indicate that Drax offer prices are significantly the lowest, whereas price differences between the other companies are statistically close to zero. Further, Drax prices appear to be less volatile. The price gap between Drax and the other companies seems only partly justifiable by differences in marginal generation costs.

2. Offer prices experience few large and very heterogeneous spikes, or many small and similar spikes, depending on the plant. Spikes are not synchronized across plants. We have detected jumps through the recursive filter introduced by Trueck, Weron and Wolff (2007).[7] E.On is the company with the highest jump frequencies (up to 0.2099, namely about one spike every 5 days), whereas spikes are more rare in the EdF time series (the jump frequency is as low as 0.034 i.e. one spike every 29 days). However, the spikes with the highest intensities are in EdF (9.936 in period 10) and BE (11.442 in period 27), and EdF is also the company whose spikes are more volatile (e.g. the standard deviation is 294.15 in period 10). Surprisingly, mean jump intensities are negative in some peak-load periods (27 and 35 for Drax, 27 for EdF, 35 for BE). The jump statistics may not be stable over time, as there were virtually no spikes before the beginning of the summer.

3. Intra-day offer price profiles vary across companies. All companies enact differentiation of their offer strategies across day-time periods, but using different intra-day profiles. Specifically, BE asks higher prices in the late morning and in the late afternoon than in other periods, tracking the intraday behaviour of APX prices quite closely. Much less related to forward prices are the offer prices submitted by the other companies. The offer prices by Drax between 8 am and 11 pm (periods 16 and 46) have virtually the same mean and variance; both the mean and variance are higher during the day. E.On's mean prices follow roughly the same profile as Drax, but volatility is higher at the beginning and at the end of the working day. EdF prices during all the afternoon settlement periods are very similar on average; the same flat pattern in observed in the morning, but corresponding to a lower level, and even lower by night. Unlike the other companies, BE seems to set its offer prices after observing the intraday updates of the APX index. This is a more information-intensive offer strategy, but one that shields the company from the uncertain behaviour of forward prices.

4. Offer prices display varying degrees of mean reversion across plants. We have run standard unit root tests, such as the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP), both on the raw series, which includes the spikes, and on the spikeless series which represent, in a sense, the "base regime" (see also Knittel and Roberts 2005, Crespo-Cuaresma et al. 2004). The null hypothesis of a unit root is rejected at the 5%

[4] The system operator is required to ensure that any acceptance it makes is consistent with the dynamic parameters of the associated BM unit, including the ramp rates and the maximum levels of imports and exports.

[5] The data are collected from the National Grid System operator's online service, which is the Balancing Mechanism Reporting System.

[6] K-median clustering requires finding *k* centers in a set of *n* points that minimize the sum of distances from the data points to their nearest centers. The k-median clustering algorithm is useful when the data have outliers or spikes. We have applied k-median clustering to de-meaned offer price data. We first identify 4 clusters per company. The sets of clusters are slightly different across companies, therefore in order to come up with "common" clusters we take their intersection. The four common clusters are: periods 1-10, 13-14, 17-29, and 33-36. Finally, we pick one half-hour within each cluster. Periods 10 and 35 correspond, respectively, the lowest and highest average demand. Periods 13 and 27 are those which, within their respective clusters, are more "distant" with respect to the union of all other clusters, based on Euclidean and Manhattan metrics.

[7] In a nutshell, the filter goes through the following steps: 1. estimate the weekly component of prices, by means of 5-days moving medians, and subtract it from the time series; 2. calculate logarithmic returns of de-weeklized prices in order to remove the mid-term seasonal and long-term trends; 3. if the log-return (for day t, weekday s) is more than 3 standard deviations away from the mean, replace the price (day t) with the median price for weekday s; 4. repeat steps 1 to 3 until the algorithm converges.

significance level by both tests for the spiky time series of BE, Drax, and Eon offer prices. In the case of EdF, the ADF test statistic for periods 27 and 35 is not significantly different from zero, meaning that the data are driven by a stochastic trend, but the PP test still suggests mean reversion. Using spikeless data, the null of a unit root rejected at the 5% level by the ADF test, except for EdF in periods 27 and 35. The PP test fails to reject for EdF (periods 27 and 35) and E.On (period 35). Notice, however, that the unit roots detected in the EdF offer prices (periods 27 and 35) may be due to two structural breaks around the beginning of July and the end of October. Overall, our mean-reversion findings are in line with the existing empirical evidence (see Bunn 2004, Weron 2006 and references therein).

Estimating ARMA-GARCH models confirms the evidence of mean reversion, also when fundamental variables are included as controls, and reveals further interesting facts. First, the speed of mean reversion is higher during the night. Second, mean reversion is stronger for Drax offer prices which, as one may recall, are also the lowest on average, while EdF and E.On offer prices in peak-load periods behave closer to random walks. After removing spikes, the estimated speed of mean-reversion is lower for all companies, showing that spikes are a very short-term source of mean reversion.

5. Offer prices are cointegrated with coal prices. While offer prices mean-revert, this is not the case for coal prices, which are found, in 2008, to be driven by a stochastic I(1) trend. Still, any closed-form solution of a strategic interaction model would yield offer prices as functions of the underlying cost parameters. We therefore test whether offer prices are cointegrated with coal prices, which are the most important fundamental variables for coal-fired plants, and we find that the null of cointegration cannot be rejected. Although we include coal price in the cointegrating relationship, we cannot reject the null of exogeneity with respect to offer prices.

6. There exist leader-follower relationships, with EdF acting as the leader in peak-load periods. A "leader" can be defined as a company whose current prices are not significantly affected by the lagged prices of competitors, but affect the subsequent prices of its competitors. Through VAR estimates, we find that EdF is a market leader in periods 27 and 35 (peak-load periods): all other companies' offer prices are significantly correlated with the lagged EdF offer prices. This evidence is confirmed when we account for cointegration between offer prices and coal prices: a shock to the long-term relationship linking EdF and coal prices in period 27 affects the short-term dynamics of the offer prices of all companies. Much the same happens in period 35, except for BE which does not follow EdF shocks.

IV. Conclusion

This paper sheds light on some novel and previously unexplored sources of offer price dispersion in the electricity balancing mechanism. We provide some puzzling evidence of offer price dispersion among plants sharing the same technological features (such as fuel, size, location). Such heterogeneity is by no means confined to price levels, but involves the very dynamic properties of offer prices, such as the rate of mean reversion, the degree of volatility persistence, the timing and intensity of spikes, the intraday price profile, and the correlation between BM offers and the forward price. This is hard to reconcile with the transparent nature of the balancing mechanism, which would rather imply convergence between offer strategies.

The detected facts are consistent with the proposed theoretical hypotheses, and suggest that, despite the bilateral nature of BM transactions, portfolio structure matters, albeit in a rather subtle way. One example is given by leader-follower relationships, which in our sample are essential drivers of offer dynamics, more so when the power demand approaches system capacity. In particular, one of the companies in our sample – EdF – is found to hold a leadership position, as the offer prices submitted by the other companies are significantly correlated with EdF's previous day offers. This confirms our hypothesis that if a company controls a significant share of imports, its competitors will find the offers previously submitted by that company as informative on the current state of the market, and shape their strategies accordingly. Such an adaptive dynamics is triggered by temporary deviations from a long-term relationship between offer prices and fuel costs, as shown by the evidence of cointegration between offer prices and coal prices. In the very short term, we find that BE offer prices track the intraday dynamics APX forward prices quite closely, suggesting a better ability of BE in dealing with intraday risk, or in economizing on the related transaction costs. BE's behaviour may also be due to its attempts to hedge its nuclear capacity. The findings about Drax offer prices confirm the hypothesis that companies not integrated in the retail segments behave more competitively.

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VII. Biographies

Derek W. Bunn is a Professor at London Business School, with research on the energy sector extending back over 30 years. Author of numerous research papers and books in the areas of forecasting, decision analysis and energy economics, he has been Editor of the *Journal of Forecasting* since 1984, a previous Editor of *Energy Economics*, and Founding Editor of the new *Journal of Energy Markets*. He has advised many international companies and government agencies in this sector.

Veli Koc (b. 1976) graduated from the University of Istanbul (2000) and completed his Diploma in Economics and Finance at the University of London, Birkbeck College (2003) and his MSc in Economics at the University of York (2004). He is currently registered as a PhD research student at the University of London, Imperial College.

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