Electricity Market Behaviour in Periods of Extreme Scarcity

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7th INFRADAY

October 10-11

Berlin

Electricity Market: Price Behaviour

- Electricity prices are known to be mean-reverting very volatile and subject to frequent price spikes.
- In many financial and commodity markets log prices is assumed to behave as a random walk.
- However in electricity prices cannot described by a random walk process this is argued by Escribano, Pe˜na, and Villaplana (2002) and Bunn and Karakatsani (2003).
- They and many other researchers consider the following characteristics of electricity prices:

- *Seasonality*
- *Volatility*
- *Mean-reversion*
- *Fat tails*
- *Jump process*

Electricity Market: Price Behaviour

- Many researchers in the literature are working on modeling and analyzing the electricity price behavior.
- Bunn(2004) developed several empirical works on linear and nonlinear time series model.
- Lucia and Schwartz (2002) and Knittel and Roberts (2005) worked on mean-reversion model with deterministic seasonal mean functions.
- Longstaff and Wang (2004) studied on the price difference observed between day-ahead and real time markets in the PJM market.
- Huisman and Mahieu (2003) argued that existence of mean-reverting process is not directly associated with jumps.
- Escribano et al. (2002) work on volatility aspects using GARCH models with possibility a jump-diffusion intensity parameter for daily spot prices from different electricity markets.
- Knittel and Roberts (2005) also include GARCH and jump processes in their model specification for hourly electricity prices.

Electricity Market: Market Power Approach

- When the reserve margin is narrow, a reduction in power generation will lead to high price spikes.

- High prices encourage generating firms to operate their power plants harder to increase their profit under the market scarcity.

- If market not fully competitive and reserve margin is low then firms can abuse market power.

- Low margin and high demand conditions give firms a very strong position to exercise market power.

- Even small firms with a small percentage of the market share could exercise market power when demand is high or margin is low.

Electricity Market: Market Power Approach

- It is likely that market power takes place during peak hours for short periods

- Wolak (2003) shows the market power in California and explain the price increase in summer of 2000.

- Since electricity is not storable and the price inelasticity of both supply and demand makes easy for firms to exercise market power.

- Borenstein, Bushnell and Wolak, 2001; Wolak, Nordhaus and Shapiro, 2000 work on empirical studies show that generators have exercised significant market power in California's wholesale electricity market.

- However, it is very difficult to distinguish between price spikes that reflect true scarcity compared to market power. Price spikes occurs even in competitive markets and those are not evident of market power.

Black-out

- We present a case study of the 27 and 28 May 2008 black-outs in the UK
- Two major power stations unexpectedly ceased supplying the system within two minutes around midday on Tuesday May 27.
- At 11.34 am Scottish Power's Longanett coal-power station with capacity of 345MW tripped.
- Two minutes later Sizewell B nuclear power station owned by British Energy (BE) suspended its full 1237MW capacity.
- The unforeseen outages forced National Grid (NG) to take extreme measures.
- However, the situation deteriorated later as nine independent generation units including Grain (E.ON), Ratcliffe (E.ON), Cottam (EdF), South Humber (Centrica) and Deseside (International Power) become unavailable during May 27.

Black-out

- The system was approximately 400MW short of capacity and as a result a black-out was inevitable in many part of the country, especially South West.

- We have employed an empirical analysis of market prices to study the linkage between reserve margins and agents' behavior in the real-time balancing and daily power exchange markets.

- We use GARCH model to measure the volatility level for APX and Offer prices from British Energy's coal power plant before during and after the black-out.

- The sample has been selected on the basis of the data availability before, during and the after the black-out, 1April – 26 May, 27-29 May, 30 May - 30 June respectively.

Black-out

- We examine the coal Offer prices for E.On, Drax, RWE Npower and British Energy before, during the after black-out.

- Also we look at the Offer prices for Oil and CCGT power plants.

- The response of British Energy, who was in large part responsible for the disruption, is of special interest in comparison with those firms whose market response was comparatively opportunistic.

Black-out

- ***We are interested in to see: how price is determined?***

- Prices are determined by economic fundamentals.
- Strategic effects of players could create spikes.
- In the period of market disruption:

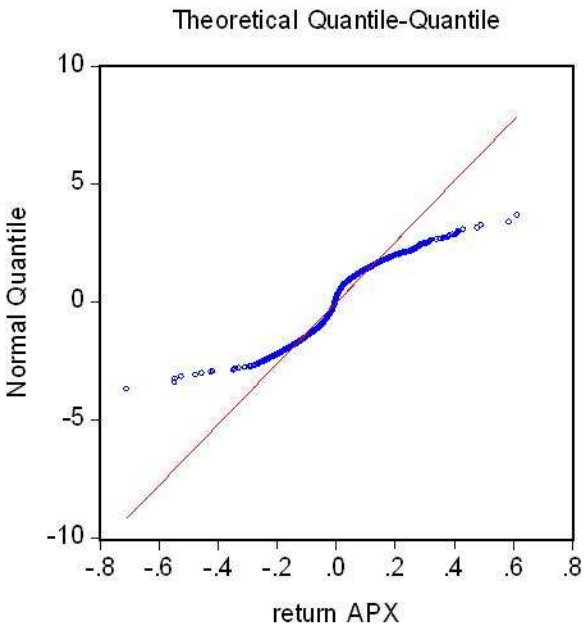
- By looking at the individual plants Offer we can say something about whether the response to market scarcity is market power opportunism on the part on some generation, or simple a competitive outcome representing a shift in the supply function.

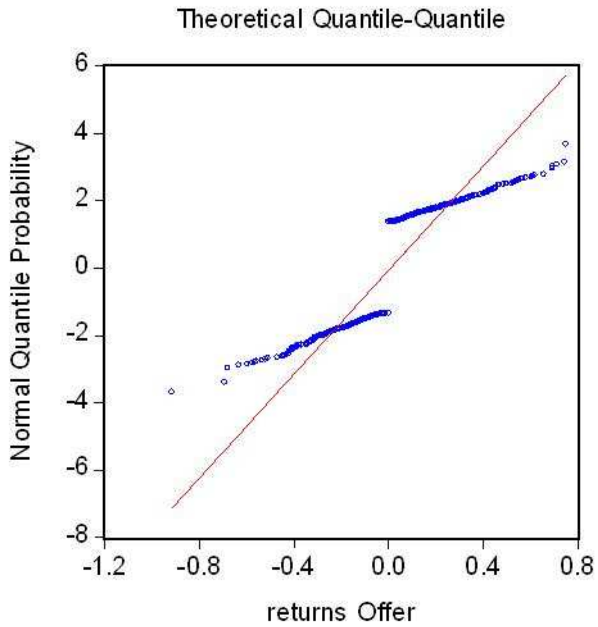
- Does the price regime shift because of Market Power or True Scarcity conditions?

Price Behaviour

Normality Test:

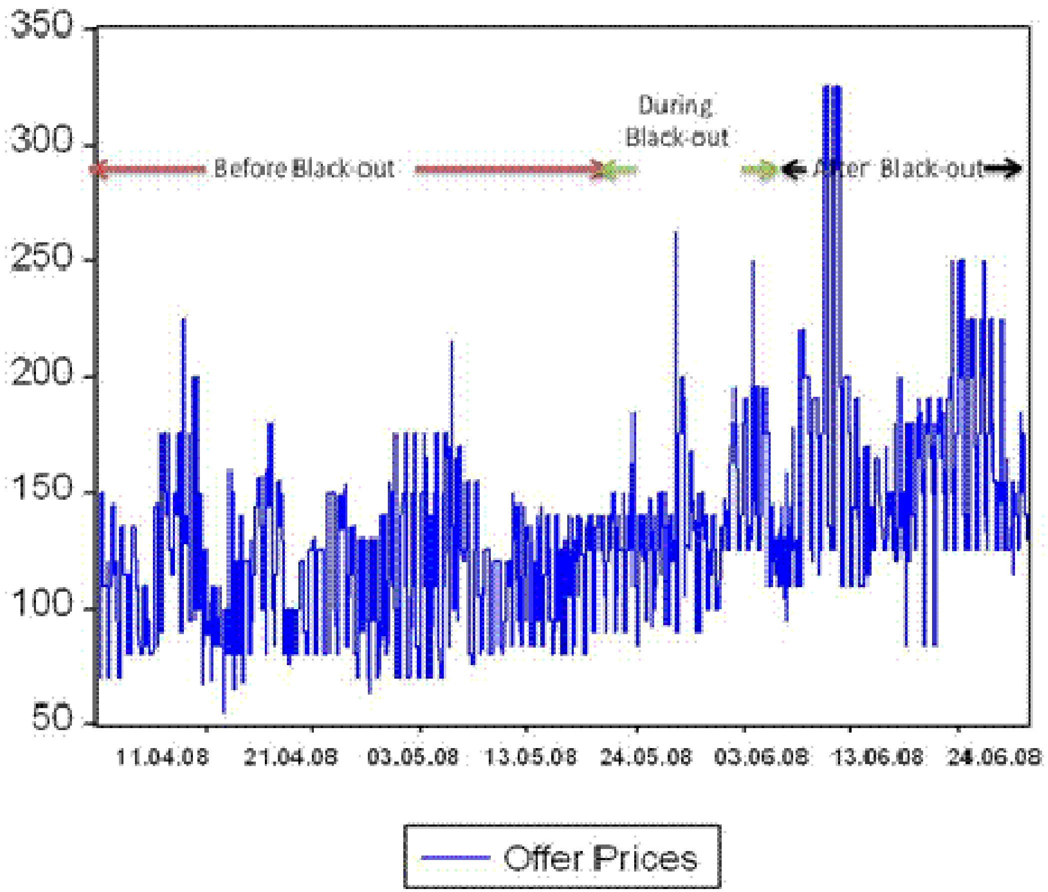
- APX and Offer in BETTA from 01/04/08 to 30/06/08. If the returns are Normally distributed then the Q-Q Plots of empirical quintile functions would be a straight line.
- We define a log return as in the classical definition where $return = \log(S_{t+1} / S_t)$





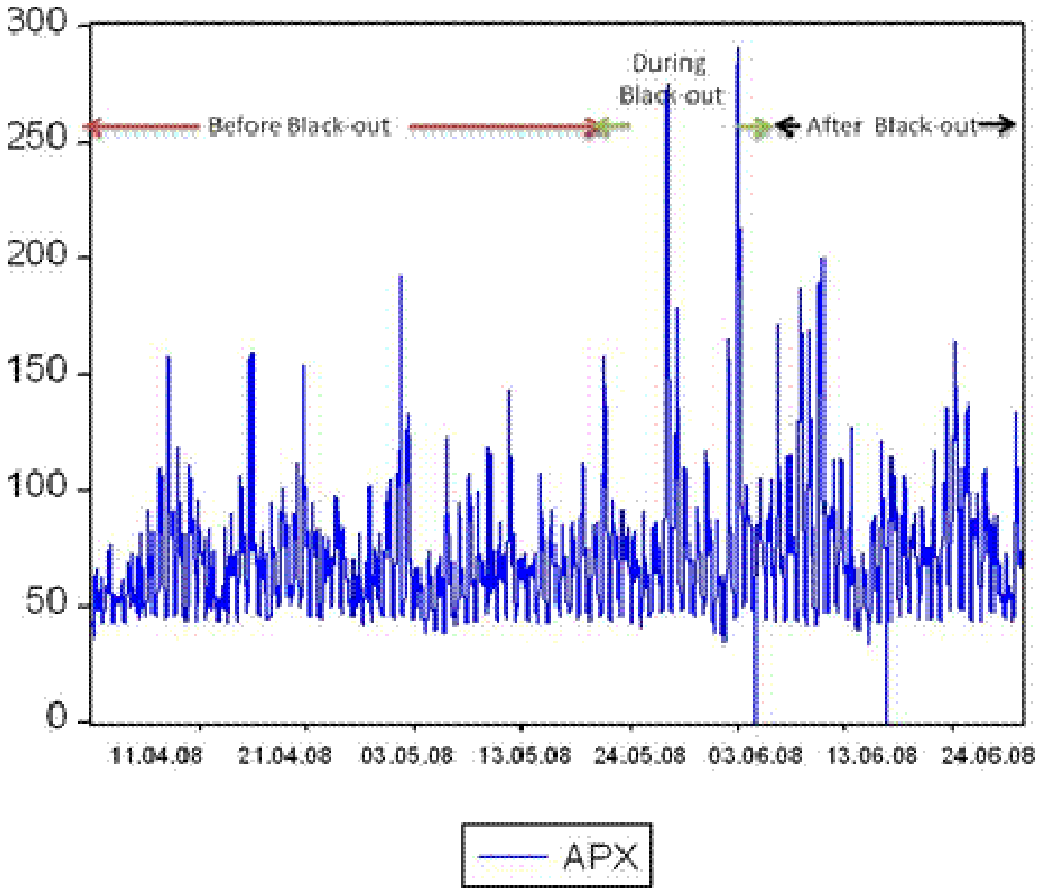
Price Behaviour

- British Energy Offer prices exhibit strong mean reversion, high volatility, seasonality and numerous large jumps especially during Black-out periods.



Price Behaviour

- APX prices exhibit strong mean reversion, high volatility and numerous large jumps especially during Black-out periods.



Price Behaviour

- Modeling and understanding the behavior of jumps is still not very well defined.
- As in this case we have three periods before, during and after black-out, and we observe price spikes during those periods.
- Price spikes have occurred before and after the black-out it may different than those has occurred during the black-out. The price spikes have occurred in these period can be caused by speculation, fuel prices or whether conditions.
- Since we know that the price spikes that occurred during the black-out period were caused by plant failure it would be interesting to compare characteristic of these spikes with those occurred in other two periods.

Price Behaviour

- In literature three different jump patterns has been developed.

1. The form one is a single jump followed by mean-reverting prices and can be negative or positive and used by Deng (2000), Villaplana (2003), and Cartea and Figueroa (2005).
2. The second jumps process is known spikes, negative or positive, it is very often observed in electricity markets. The jumps follow by a reserve jump of the same magnitude on the next day. Huisman and Mahieu (2003) model this type of jumps by a regime-switching model.
3. Third one is the set of jumps occurs in a short time period which can be positive or negative or mixed. De Jong and Huisman (2002) applied a regime-switching model that switching between a mean reversion and a pure jump regime.

- Seifert and Uhrig-Homburg (2006) proved a common model that allows to unite the main jumps patterns observed and compare the effectiveness of different jump specifications.

Firms Behavior

- In our case we will develop a similar model to see jumps behaviour for each periods.
- Tables in below shows the summary of descriptive statistics of the APX, Bid, Offer, SBP and SSP (in £/MWh) before, during and after the Black-out.

Before Black-out : 1 April - 26 May

	APX	BID	OFFER	SBP	SSP
Mean	66.36	35.34	117.31	82.62	54.92
Median	63.60	42.58	119.98	72.04	45.97
Maximum	193.30	48.63	224.98	362.00	178.51
Minimum	36.88	0.98	54.99	36.88	0.88
Std. Dev.	19.66	16.45	30.24	37.46	19.93
Skewness	1.34	-1.49	0.38	1.80	1.90
Kurtosis	5.68	3.29	2.90	7.98	7.49
Jarque-Bera	1575.68	979.37	63.11	4145.72	3813.14

Firms Behavior

During Black-out : 27 - 29 May

	APX	BID	OFFER	SBP	SSP
Mean	95.35	31.53	145.46	149.42	82.87
Median	78.38	36.92	139.99	90.25	49.24
Maximum	274.89	48.49	262.50	560.20	274.89
Minimum	47.90	2.25	89.99	47.90	35.10
Std. Dev.	53.43	18.83	35.47	118.40	57.29
Skewness	1.87	-0.69	0.60	1.39	1.96
Kurtosis	6.60	1.76	3.11	4.45	6.58
Jarque-Bera	162.04	20.55	8.60	59.21	169.23

After Black-out : 30 May-30 June

	APX	BID	OFFER	SBP	SSP
Mean	77.50	28.74	156.32	87.90	55.73
Median	72.33	46.78	144.98	77.30	49.29
Maximum	290.75	51.64	324.98	300.31	282.37
Minimum	0.00	2.25	84.97	34.19	9.60
Std. Dev.	32.75	23.13	43.30	41.57	27.76
Skewness	2.10	-0.27	1.50	1.37	3.27
Kurtosis	10.50	1.08	6.40	5.06	18.36
Jarque-Bera	4724.47	252.89	1317.95	751.38	17845.31

Firms Behavior

- Table shows that average prices for all of the prices have increased during the black-out and they remain higher after black-out except Bid prices.

- The distributional properties of the prices appear non-normal; Jarque-Berra test has been rejected for normal distribution.

- Excluding the Bid prices, all of the prices are positively skewed.

- During the Black-out SBP prices are the most volatile, whereas bid prices are the least volatile.

- However, after the black-out Offer prices are the most volatile.

Firms Behavior

- The standard errors of deviation before during and after the black-out are shown below table. As we can see from the table black-out have a big impact on market prices.
- Based on the samples, there is insufficient evidence at the 5% level of significance to conclude that the mean prices differ between before, during and after the black-out.
- The most mean price difference is the SBP on the period of during and after the black-out which is 10.92.
- The least mean price is the BID prices.

	Diffrence between mean		
	Before- During	During-After	Before - After
APX	4.8	5.2	1.21
BID	1.8	2.1	0.9
OFFER	3.5	4.06	1.69
SBP	10.5	10.92	1.78
SSP	5.1	5.4	1.09

GARCH

- A GARCH model is developed to measure the volatility of the Offer and APX prices before, during and after the black-out.

$$Offer = \alpha + \gamma_1 Offer_{t-1} + \gamma_2 \text{Margin}_t + \varepsilon_t$$

$$APX = \alpha + \beta_1 APX_{t-1} + \beta_2 \text{Margin}_t + \beta_3 \text{Margin}_{t\text{-}1} + \beta_4 \text{Margin}_{t-2}$$

$$+ \beta_5 \text{Demand}_t + \beta_6 \text{Demand}_{t-1} + \varepsilon_t$$

- Where ε_{t} iid and $E(\varepsilon_t, \varepsilon_{t\text{-}1}) = 0$

- Varince model:
- The GARCH (1,1) model

$$\sigma_{ut}^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{ut-1}^2$$

GARCH

- The long term volatility level depends on the estimates of constant parameter α_0.
- The parameter estimates α_1 and β_1 reveal some information on volatility process.

- The large β_1 indicate that shocks to conditional variance take a long time die out, so volatility is persistent.
- Large values of α_1 indicate volatility reacts quite intensively to market movements
- So if α_1 is relatively high and β_1 is relatively low then volatilities tend to be more spiky.

GARCH

$$Before\ \sigma_{ut}^2 = 1.57 + 0.015\varepsilon_{t-1}^2 + 0.97\sigma_{ut-1}^2$$

$$During\ \sigma_{ut}^2 = 132.24 + 1.08\varepsilon_{t-1}^2 - 0.0093\sigma_{ut-1}^2$$

- There are huge differences between α_0 estimates of each volatility regime.
- The parameter estimates α_0 in during volatility is greater than parameter estimates α_0 before black-out

GARCH

- Comparing the before and during the black-out period:
- We observed before black-out have lover α_1 estimates but higher β_1 estimates.

- So, the GARCH process are more reactive before black-out but less persistent than that in the during black-out.

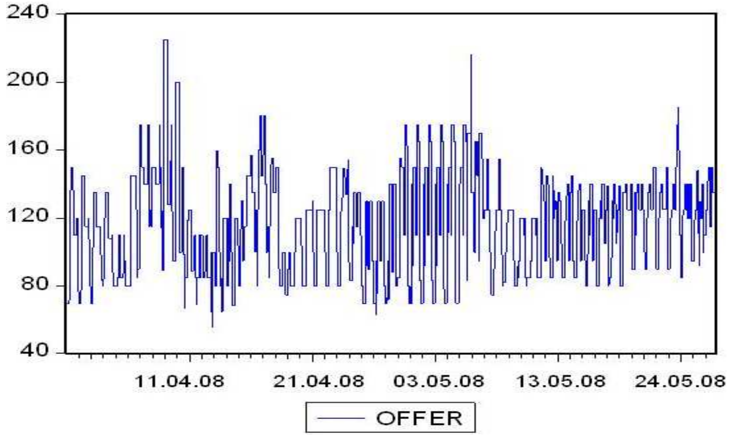
- The speed of mean-reversion is determined by the estimated parameter value of γ_1 from AR(1) functions for during and after black-out periods.

- During the black-out is the faster the price moves toward its long-run mean than other two periods.

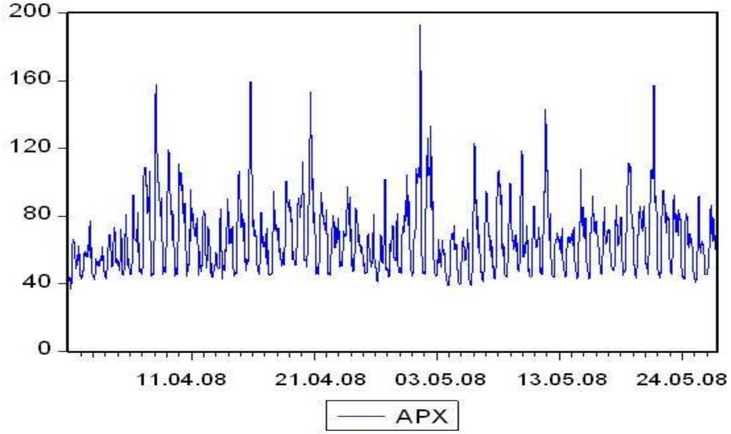
Test Volatility

- *Before black-out*

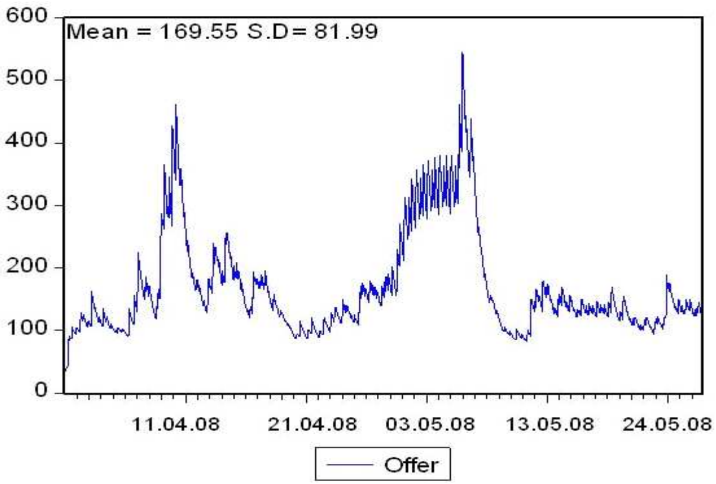
Half-hourly Offer Price



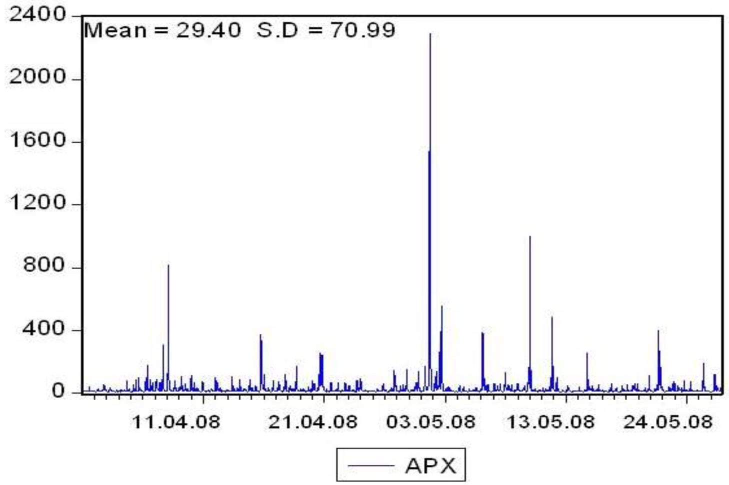
Half-hourly APX Price



Volatility of Offer Prices



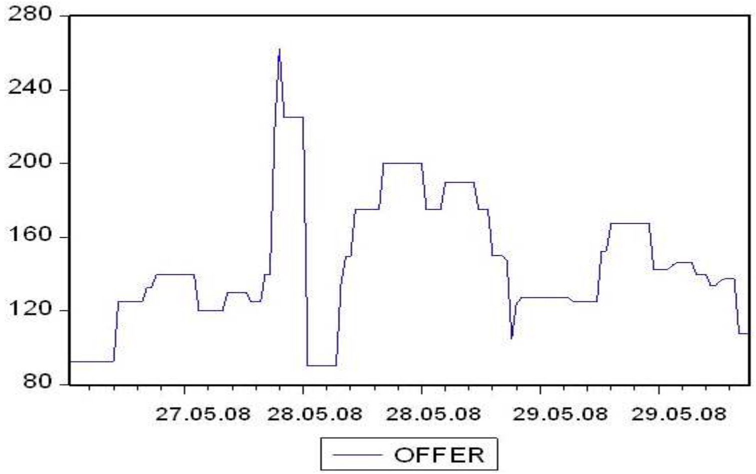
Volatility of APX Prices



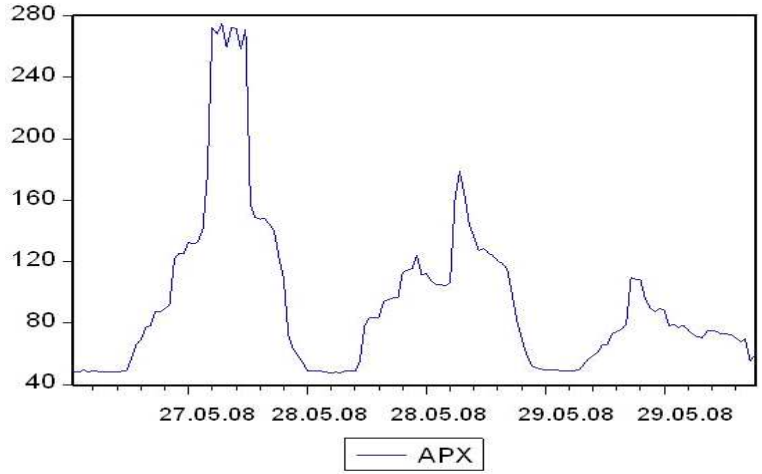
Test

- *During black-out*

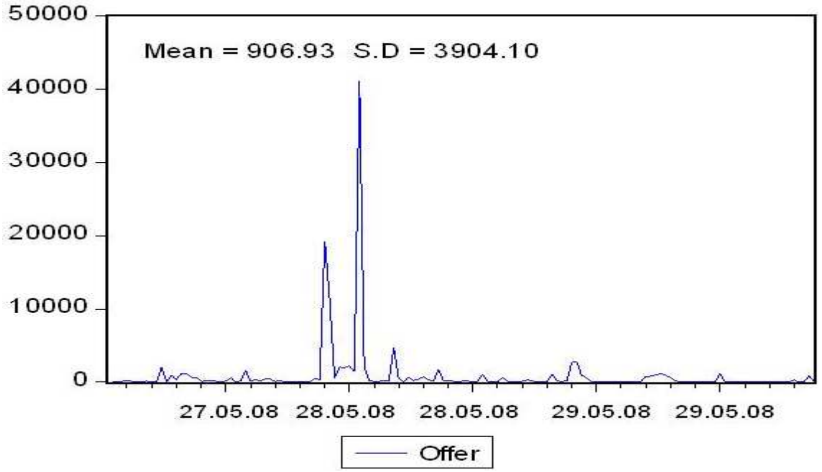
Half-hourly Offer Price



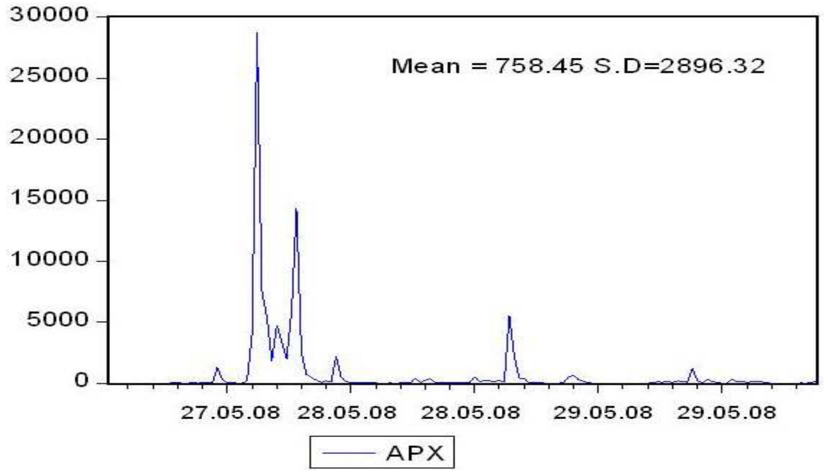
Half-hourly APX Prices



Volatility of Offer Prices



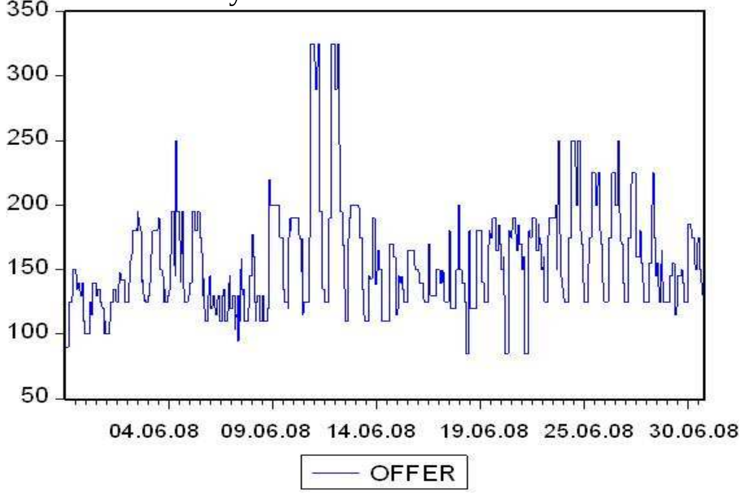
Volatility of APX Prices



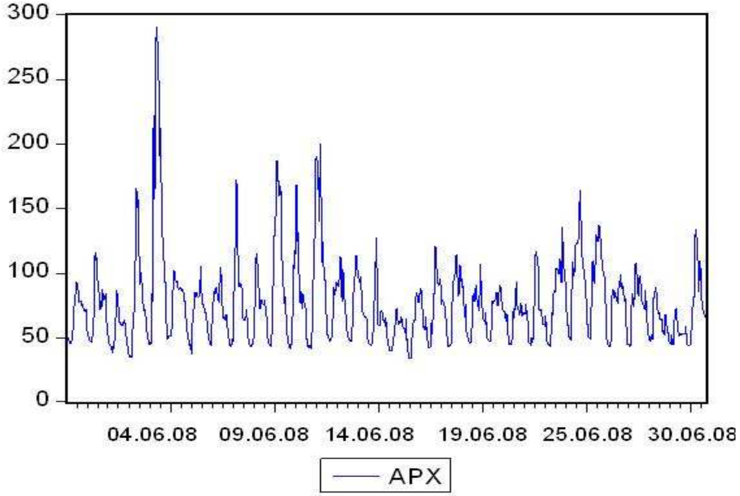
Test

- *After black-out*

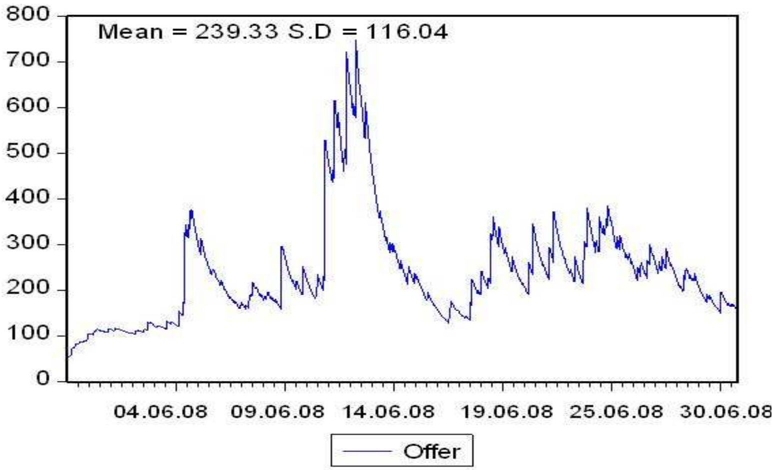
Half-hourly Offer Price



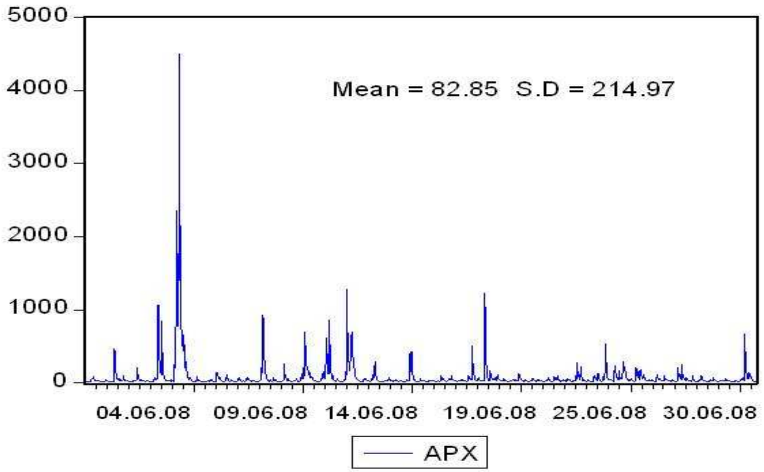
Half-hourly APX Price



Volatility of Offer Prices



Volatility of APX Prices



Market Power

- Behavior of power generation companies during the May black-out :
- Generating firms generally agree that price should be allowed to raise to reflect true scarcity.

Date	BE Bid	BE Offer	Drax Bid	Drax Offer	Eon Bid	Eon Offer	RWE Bid	RWE Offer
Before								
Mean	35.3	117.3	42.7	89.2	43.3	103.9	-365[illegible].1	113.0
Median	42.6	120.0	43.1	90.0	43.5	104.0	39.1	105.5
Maximum	48.6	225.0	46.3	150.0	49.2	150.0	48.0	225.0
Minimum	1.0	55.0	38.2	60.0	15.5	54.6	-99999.0	63.7
Std. Dev.	16.4	30.2	1.8	12.6	3.2	20.3	48193.6	34.1
Skewness	-1.5	0.4	-0.1	1.4	-4.4	-0.6	-0.6	1.6
Kurtosis	3.3	2.9	2.4	7.2	40.4	2.6	1.3	5.7
Jarque-Bera	979.4	63.1	48.3	2835.2	162326.1	178.1	450.6	1911.5
During								
Mean	31.5	145.5	45.3	99.5	46.0	141.6	-15242.5	176.6
Median	36.9	140.0	46.4	90.0	48.1	165.0	46.2	130.0
Maximum	48.5	262.5	47.5	110.0	48.5	165.0	47.4	300.0
Minimum	2.3	90.0	41.7	90.0	37.9	79.3	-99999.0	68.0
Std. Dev.	18.8	35.5	2.2	10.0	3.4	32.7	36117.5	69.5
Skewness	-0.7	0.6	-0.5	0.1	-1.1	-0.7	-1.9	0.8
Kurtosis	1.8	3.1	1.6	1.0	2.3	1.7	4.7	2.2
Jarque-Bera	20.6	8.6	18.6	23.8	29.2	23.7	107.3	19.4
After								
Mean	28.7	156.3	47.0	99.1	47.2	249.4	-47356.2	144.2
Median	46.8	145.0	47.6	95.0	48.5	225.0	-5000.0	150.0
Maximum	51.6	325.0	51.6	200.0	52.5	500.0	55.0	300.0
Minimum	2.3	85.0	34.6	73.9	23.1	61.1	-99999.0	70.0
Std. Dev.	23.1	43.3	3.2	18.6	4.4	123.6	49611.3	42.3
Skewness	-0.3	1.5	-0.5	1.2	-1.6	0.4	-0.1	0.4
Kurtosis	1.1	6.4	2.2	7.0	7.9	2.1	1.0	4.2
Jarque-Bera	252.9	1317.9	104.4	1387.3	2219.9	91.2	255.4	135.6

Market Power

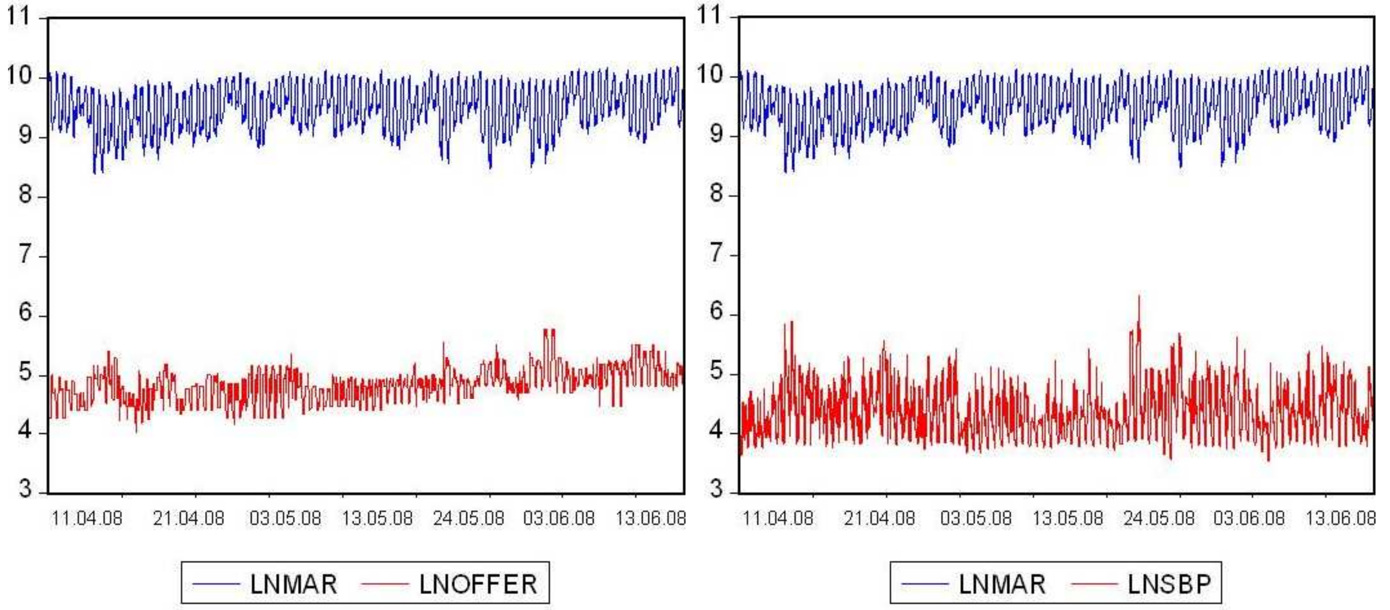
- All four power generators has increased their Offer prices during the black out and prices remain high after the black-out.
- Coal-fired power plant is very active in the BETTA balancing market and they operate during peak and off peak period.

- The entire 1237-MW Sizewell B nuclear power station own by British Energy (BE) has failed and caused the black-out. British Energy might have inside information and move first to offer high prices. However, our empirical analysis with VAR model has not proved this is the case during this black-out.

- Figure below show all four coal power plants offer behaviour during 01 Aprial-30 June. During black-out as we can see price spikes has occurred, maximum price has Offered by Eon which is 500MWh.

Market Power

Half Hourly prices for logOffer and logMargine in during 01.04.2008 – 30.06.2008

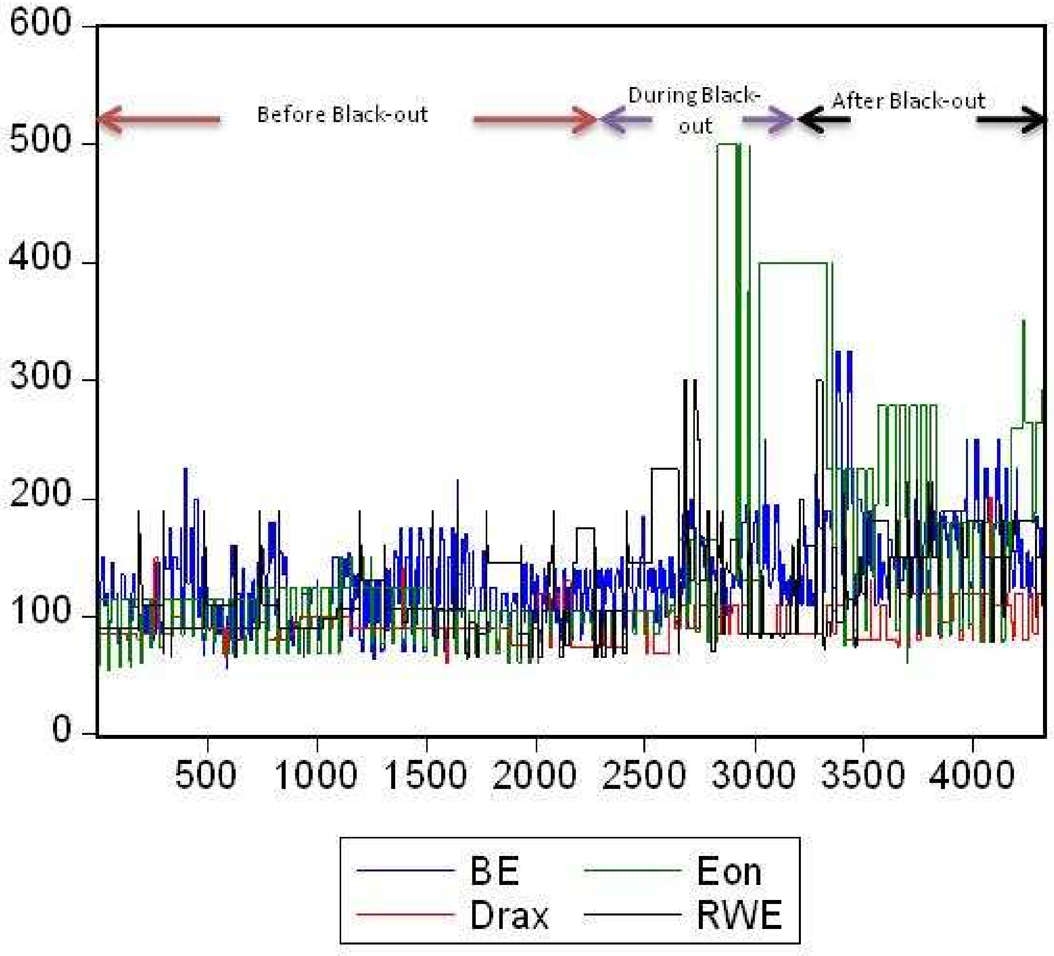


Reduction of the margin due to outages can cause price spikes, because more expensive power plants such as oil and CCGT more likely to be scheduled to unscheduled outages.

- As we can see those jumps occur when the system margin is low.

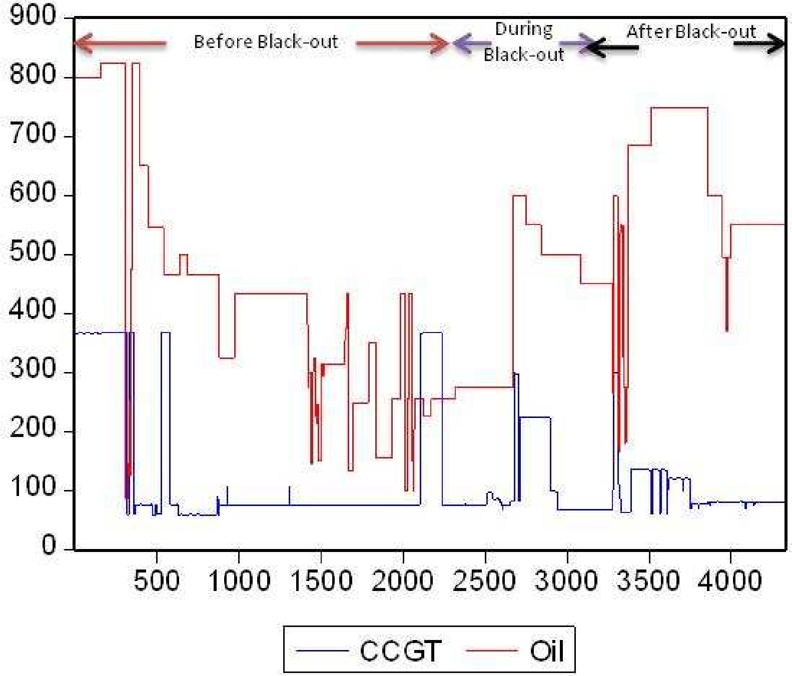
Market Power

- RWE Npower, Eon, British Energy and Drax coal power plants Offer price behaviour.



Market Power

- ***Oil and CCGT Case:***
- Oil power plants normally submits a very high offer prices to the Balancing Market when demand is peak.
- These two power plants respond to the black-out and made very high Offer prices.



Market Power

Date	CCGT-Bid	CCGT-Offer	Oil-Bid	Oil-Offer
Before				
Mean	-20283.8	132.6	-99165.3	410.2
Median	38.2	75.0	-99999.0	435.0
Maximum	45.0	370.0	45.0	825.0
Minimum	-99999.0	58.0	-99999.0	86.0
Std. Dev.	39383.5	118.9	9095.9	193.3
Skewness	-1.5	1.5	10.8	0.9
Kurtosis	3.2	3.2	118.0	3.0
Jarque-Bera	992.2	981.4	1506446.0	347.8
During				
Mean	39.9	191.6	-99999.0	523.6
Median	39.0	225.0	-99999.0	600.0
Maximum	44.9	300.0	-99999.0	600.0
Minimum	38.7	75.0	-99999.0	275.0
Std. Dev.	1.7	81.5	0.0	124.4
Skewness	1.8	-0.4	NA	-1.4
Kurtosis	4.8	1.7	NA	3.2
Jarque-Bera	92.9	13.5	NA	50.1
After				
Mean	18.1	101.4	-98435.7	576.5
Median	38.0	80.0	-99999.0	550.0
Maximum	48.0	300.0	53.6	750.0
Minimum	-5000.0	60.0	-99999.0	165.0
Std. Dev.	314.4	49.2	12412.1	123.7
Skewness	-15.9	2.1	7.8	-0.3
Kurtosis	253.8	7.2	62.0	3.3
Jarque-Bera	4089694.0	2259.5	238524.0	28.1

Market Power

- As we can see average prices for oil power plant is 523.6 and for CCGT is 191.6 during balk-out.

- But, we don’t know how much of the increase in prices is the result of the exercise of market power versus and how much is from the true scarcity.

- In this regard, how true market scarcity explains the behavior of the price spikes?

- We don’t have evidence to put forward to show that price spikes during black-out resulted only opportunistic generators behavior with exercising their market power.

Summary

- We need to expand our research to develop a model to show that the price spikes have occurred during the black-out period had caused by plant failure so it would be interesting to compare characteristic of these spikes with those occurred in other two periods.
- And also we need to include other factors such as oil and gas prices, emission prices as well.
- Also, geographical location of plants need to be consider.
- Interconnection of lines can be a reason for a market power abuse.