

Revenues from storage in a competitive energy market: empirical evidence from Great Britain

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Monica Giuliatti, joint work with:

Luigi Grossi (Universita' di Verona) and Michael Waterson (University of Warwick)

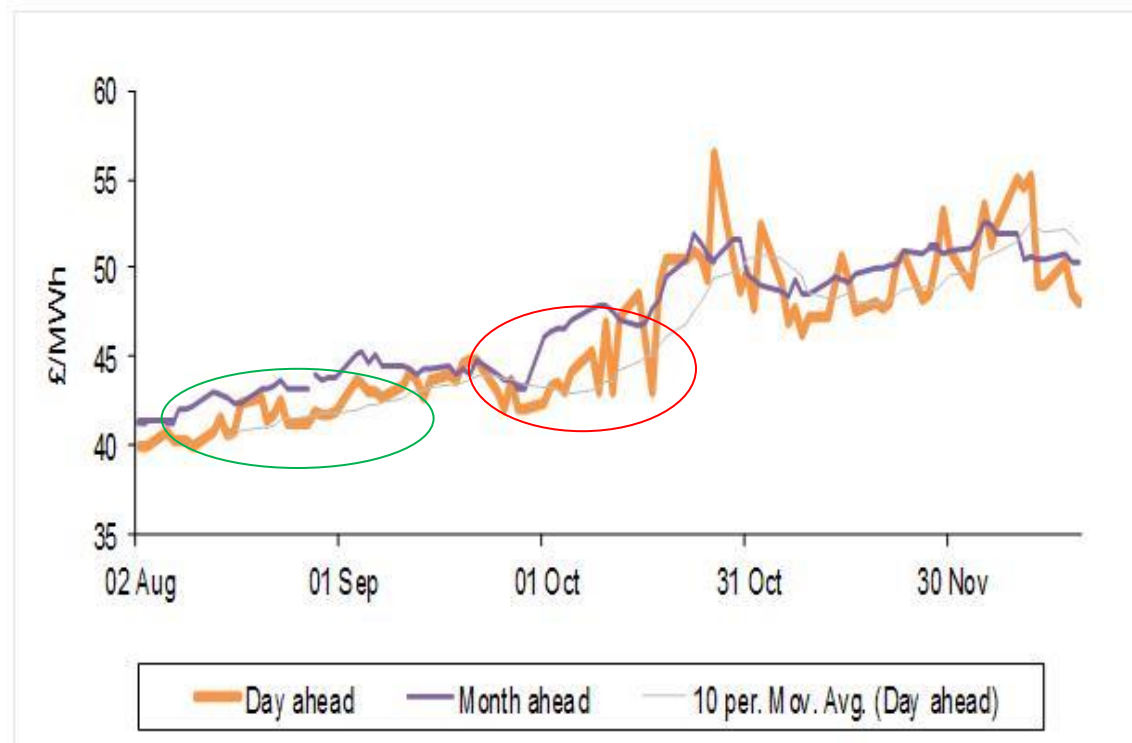
Introduction and motivation

- ⦿ Increased role of intermittent renewable sources of energy makes storage a desirable option, despite cost
- ⦿ Main focus on wind power and ability to deal with week-long calms
- ⦿ Energy storage facilities will be provided through a market system, rather than being subject to command imperatives
- ⦿ Given existing energy market system, what arbitrage conditions make it privately worthwhile to build and run the facility?

The 'park spread' concept

- Storage facility arbitrage strategy which maximises the expected profits, while limiting the risk associated with price volatility (risk free strategy).
- Storage can participate in the forward market buying electricity when prices are low and selling it for delivery at time T in the future.
- The inter-temporal price gap needs to meet at least a 'conservative' efficiency rate of the facility (current technology: 60-70%).

Observed price patterns (2004)



The park-spread index

- Profitability of storing power purchased at time t and sold on the same day in the forward market for delivery in the future N periods ahead can be defined as:

$$\frac{F_{t,t+N} - S_t}{S_t}$$

- The owner of the storage facility aims to exploit arbitrage opportunities to discharge at a point in the future for given levels of round trip efficiency.

Data source:

Platts UK Power Market database

- **Day-ahead** power assessments, base load and peak price.
 - **Baseload assessments** refer to delivery from 23:00 on the day of trade to 23:00 the day after
 - **Peak assessments** are for delivery 7:00 to 19:00 on the day following trade
- **Week-ahead** power assessments, peak (for delivery Monday to Friday the following week).
- **Month-ahead** peak assessment for delivery in the 4(5) weeks following trade.
- Daily frequency (5 working days) from March 2001 to November 2012. All prices measured in £/MWh.

Analysis of profitability conditions

| Year | | 60% | 70% | Year | | 60% | 70% |
|-------------|--------|-----|-----|-------------|--------|------|------|
| 2001 | rdb.wp | 0 | 0.1 | 2007 | rdb.wp | 0.06 | 0.22 |
| | rdb.mp | 0 | 0.3 | | rdb.mp | 0.22 | 0.41 |
| 2002 | rdb.wp | 0.1 | 0.2 | 2008 | rdb.wp | 0.03 | 0.1 |
| | rdb.mp | 0.1 | 0.3 | | rdb.mp | 0.07 | 0.15 |
| 2003 | rdb.wp | 0.1 | 0.3 | 2009 | rdb.wp | 0 | 0 |
| | rdb.mp | 0.2 | 0.4 | | rdb.mp | 0 | 0.03 |
| 2004 | rdb.wp | 0.1 | 0.2 | 2010 | rdb.wp | 0 | 0 |
| | rdb.mp | 0.1 | 0.3 | | rdb.mp | 0 | 0 |
| 2005 | rdb.wp | 0 | 0.1 | 2011 | rdb.wp | 0 | 0 |
| | rdb.mp | 0 | 0.2 | | rdb.mp | 0 | 0 |
| 2006 | rdb.wp | 0.1 | 0.2 | 2012 | rdb.wp | 0 | 0 |
| | rdb.mp | 0.2 | 0.4 | | rdb.mp | 0 | 0 |

Day-ahead (baseload) to week-ahead (peak), Day-ahead (baseload) to month-ahead (peak)

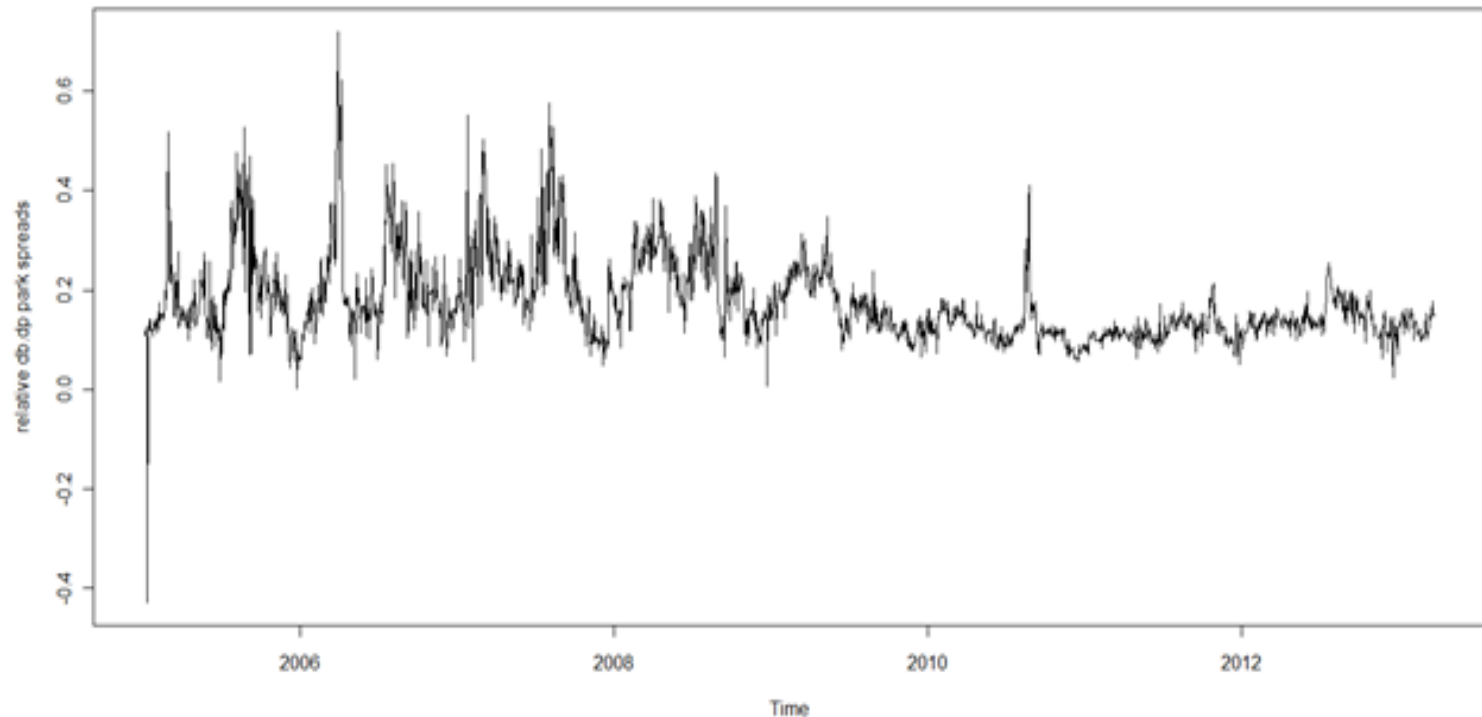
Summary of results (1)

- Profitable gaps between day-ahead and forward prices which are compatible with efficiency rates are observed with reasonable frequency over a period 10 years, especially around 2005-2008, but not in the last 3 years.
- Occurrence of profitable arbitrage opportunities is more prevalent with monthly horizon and for the higher level of round trip efficiency (70%).

Short term arbitrage opportunities

- ⦿ Limited arbitrage opportunities over medium to long term
- ⦿ Trading base load Vs peak power intra-day exploits higher efficiency of the electricity system
- ⦿ Illustrated by baseload Vs peak returns intra-day
- ⦿ This could make forms of storage such as batteries profitable for sufficient levels of capacity

Day ahead peak – base load returns



Returns on average about 20%, but lower after 2009/2010

Modelling the 'the park spread': methodology

- Stationarity tests: KPSS (no unit root) and Phillips-Perron (unit root)
- Seasonal ARIMA leading to residuals which are nearly white-noise (residual noise due to intra-day aggregation).
- Extreme value theory – suitable to model markets with a pattern of D-S imbalances (rather than anomalous behaviour).

Stationarity analysis: park spread measure

| | Day ahead baseload day ahead peak | Day ahead baseload Week ahead peak | Day ahead baseload Month ahead peak |
|--|---|--|--|
| KPSS test statistic (H_0 no unit root) | 0.263 | 0.251 | 0.166 |
| Test critical values (1% level) | 0.216 | 0.216 | 0.216 |
| Test critical values (5% level) | 0.146 | 0.146 | 0.146 |
| Phillips-Perron test statistic (H_0 unit root) | -11.979 | -15.548 | -10.007 |
| Test critical values (1% level) | -3.968 | -3.968 | -3.968 |
| Test critical values (5% level) | -3.415 | -3.415 | -3.415 |

Dynamic analysis: ARIMA model

| | Day ahead baseload Day ahead peak | Day ahead baseload Week ahead peak | Day ahead baseload Month ahead peak |
|--|---|---|--|
| SAR1 coefficient | 0.6979 (***) | 0.6040 (***) | 0.7180 (***) |
| Intercept | 8.3914 (***) | 9.2110 (***) | 10.7162 (***) |
| Adjusted R² (seasonal regression with dummies) | 0.7497 | 0.6462 | 0.8155 |

Seasonal ARIMA(1,0,0) model
with weekly seasonality (5 working days)

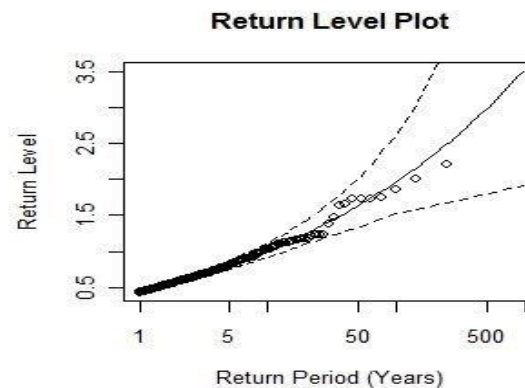
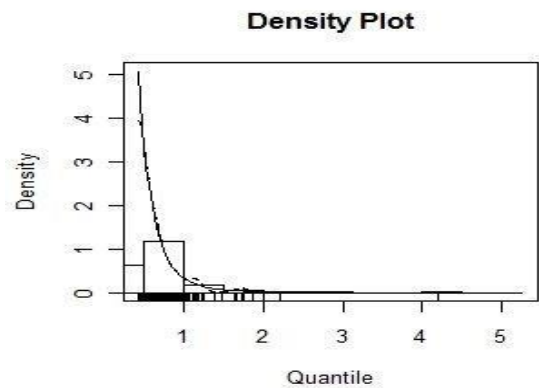
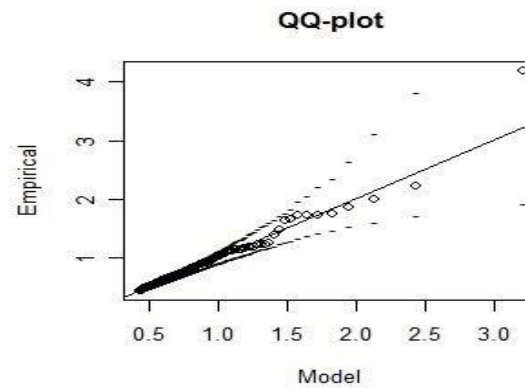
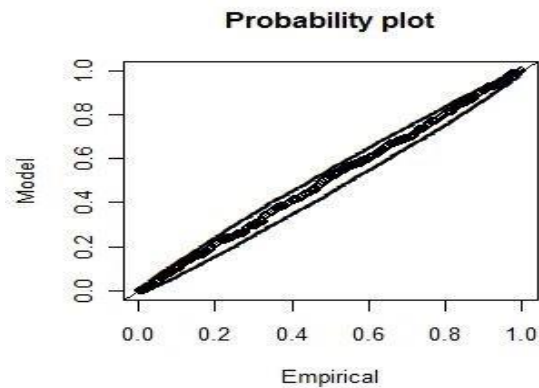
Summary of results (2)

- The stationarity analysis points towards integration of order 1, leading to a model in first differences
- The park spread measures modelled as ARIMA(1,0,0) with 5 periods seasonality generate nearly white noise residuals (with discrepancies due to intra-day aggregation).

Extreme value theory analysis

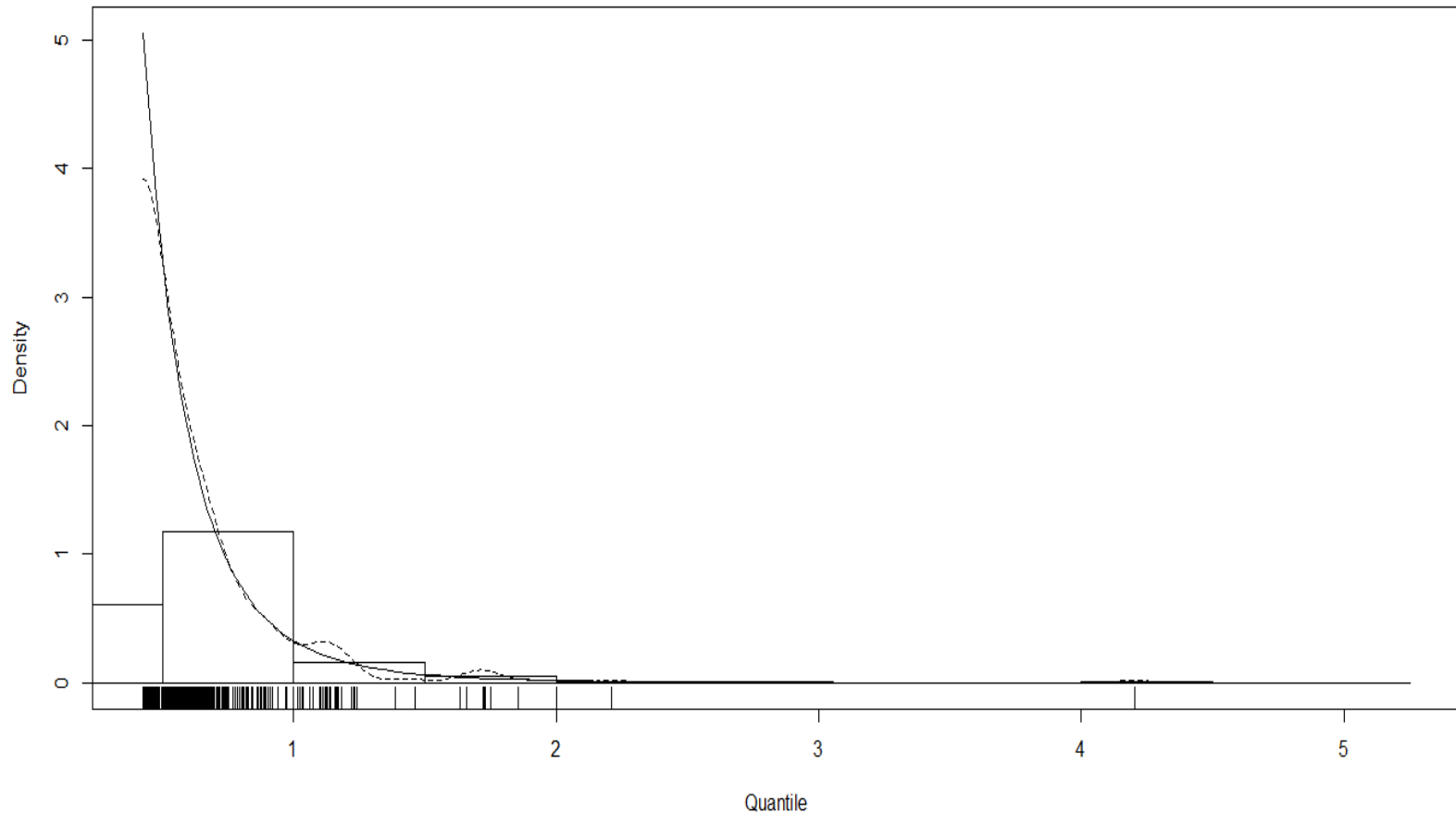
- Threshold for extreme values exogenously determined by technology, round trip efficiency implies thresholds of 0.6 and 0.429 respectively
- Insufficient observations for reliable analysis for 60%.
- At 70% r.t.e. we have 335 observations. 11.5% of the observations for the original series
- With 11.5% of observations we estimated a Generalized Pareto distribution which satisfactorily fits the theoretical one (density plot). Both form and scale parameters are highly significant.
- Same process for SARIMA residuals to check for autocorrelated effects, this generates even better fit.

Extreme values analysis: original series (70% r.t.e.)



Extreme values analysis: park spread measure (70% r.t.e.)

Density Plot



Summary of results (3)

- We adopt EVT as method to assess the likelihood of arbitrage opportunities arising in the forward markets in future periods (rather than predicting expected returns).
- We are able to model and forecast the extreme values which make the exploitation of arbitrage opportunities profitable for the highest level of round trip efficiency, with up to 1 year horizon.

Conclusions

- Despite their social benefits, if storage facilities are to be provided privately their commercial appeal will depend on their expected profitability.
- One potential source of profitability is the exploitation of arbitrage opportunities in forward markets.
- Evidence from the UK indicates that these opportunities were present in the last decade but have not been observed in the last 3 years (impact of economic recession?).
- Extreme value theory can be used effectively to forecast arbitrage opportunities up to one year ahead

Thank you