Properties of Electricity Prices and the Drivers of Interconnector Revenue

Vladimir Parail

University of Cambridge

EPRG 18.01.10
Definitions

• Interconnection vs. transmission
  – Inter-market vs. intra-market
  – Under jurisdiction of 2+ TSOs

• Why make the distinction?
  – Allocation of costs is difficult
  – Coordination between TSOs (Brunekreeft, 2003)
  – Intra-market constraints often not priced
Definitions (cont...)

• Market based investment
  – Evaluated on the basis of private benefits
  – Arbitrage revenues from trading
  – Capacity may be auctioned

• Features
  – Only feasible with directional flows
  – Transmission constraints priced explicitly
NorNed and BritNed

700MW

1,000MW
Background

• Previous EPRG paper on NorNed
  – Estimates price effects
  – Motivates merchant interconnection from social perspective

• NorNed profits higher than expected
  – Forecast annual operating profit was €64m
  – Actual profit in first 2 months was €50m
Motivation

- Create a detailed evaluation framework
- Profit-motivated investment
- Focus on drivers of revenue
- Trade on an interconnector resembles financial arbitrage
- Interconnection capacity is a financial asset
- Adapt tools borrowed from finance
Overview

- Simulation methodology
- No “bottom-up” simulation
- Based on properties of wholesale prices
- Properties extracted from historic data
- Split into stochastic and deterministic elements
- Applied to NL, NO and GB
Preview of Conclusions

• Stochastic properties of prices are important in determining interconnector revenues
• Interconnectors between very similar markets can be profitable
• Intuition and generalisations may turn out to be wrong without modelling
• Changes in fuel prices are not a major driver of interconnector revenues
Historic prices: monthly moving average

NorNed comes online

- NO price
- NL price
- GB price

www.electricitypolicy.org.uk
Historic prices: daily and weekly variation

![Graph showing historic prices: daily and weekly variation](image)

- **NO price**
- **NL price**
- **GB price**

---

**www.electricitypolicy.org.uk**
Estimating deterministic properties

• Predictable variation
  – Intra-day
  – Intra-week
  – Seasonal

• Average historic reservoir levels in Norway
  – Limited explanatory power
  – Deviations from expected level unpredictable
Estimating deterministic properties (cont...)

- Estimated using an ARMA model

\[ y_t = \sum_{i=1}^{K} x_{it} \beta_i + \mu_t \]

\[ \mu_t = \sum_{p=1}^{P} \phi_p \mu_{t-p} + \sum_{q=1}^{Q} \theta_q \varepsilon_{t-q} + \varepsilon_t \]

- Hourly observations
- Estimated by Maximum Likelihood
Fuel and electricity prices

- Observed properties
  - Electricity prices more volatile than fuel prices
  - Significant deviations from long-run relationship
  - NL electricity price unaffected by coal price

- NL dominated by gas powered CHP
- More balanced generation mix in GB

www.electricitypolicy.org.uk
Fuel and electricity prices: NL
Fuel and electricity prices: GB
Fuel and electricity prices: Estimation

- Vector Error Correction Model

\[ P_t^E = \alpha + \beta P_t^F + \varepsilon_t \]

\[ \Delta P_t^E = a + \gamma (CI_{t-1}) + \sum_{i=1}^{N} b_i \Delta P_{t-i}^E + \sum_{i=1}^{N} c_i \Delta P_{t-i}^F + \mu_t \]

\[ \Delta P_t^F = d + \delta (CI_{t-1}) + \sum_{i=1}^{N} e_i \Delta P_{t-i}^F + \sum_{i=1}^{N} f_i \Delta P_{t-i}^E + \eta_t \]
Fuel and electricity prices: Estimation

• Cointegrating relationships
  – NL electricity and gas prices
  – GB electricity and gas prices
  – GB electricity and coal prices

\[ \beta \approx 1 \]

• Proportional relationship in prices
• Lower confidence in electricity and EU ETS relationship
Stochastic properties of prices

• Unpredictable residual price variation
  – Fuel and EU ETS price variation
  – Unobserved determinants of prices
  – Varying effect of observed determinants

• Properties of empirical distribution
  – Irregular shape
  – Correlated residuals
NO regression residuals
Autocorrelation of NO price shocks
Bootstrapping

• Rationale
  – Autocorrelation distorts the distribution
  – Local peaks and skewedness
  – Long investment horizon for interconnectors
  – Need a history-independent unbiased forecast

• Summary
  – Repeated sampling with replacement
  – Artificially increases sample size
Bootstrapping (cont...)

- Standard bootstrap (Efron, 1979) fails for dependent data
- Block bootstrap (Kunsch, 1989) preserves dependence within blocks
- Sieve bootstrap (Buhlmann, 1997)
  - Approximates the block bootstrap
  - Better finite sample properties
  - 2,190 blocks of 2,190 hours generated
Bootstrap distribution of NO price shocks

Distribution of residuals vs. Normal distribution

Frequency

[Graph showing the distribution of residuals compared to a normal distribution]
Simulating prices

• Deterministic components generated from regression results

• Simulating stochastic shocks is harder
  – GB distribution approximated by normal
  – Fat-tailed distribution for NL and NO
  – No matching symmetric parametric distribution
  – Correlation in stochastic shocks
Simulating stochastic shocks

- Simulate positive and negative halves of each distribution separately
- Each half approximated by Weibull distribution
  - Parameters found by maximising log likelihood given the data
  - Positive and negative halves of distribution stitched together
Simulating stochastic shocks: NO

- Frequency
- Residuals distribution
- Simulated distribution

www.electricitypolicy.org.uk
Generating correlated shocks

- Fuel price and wind output shocks
- Correlation between different distributions
- Spearman’s rank correlation
  - X and Y can be related by any monotonic function
- Simulate correlated random variables from different distributions
Generating correlated shocks (cont...)

For any random variable $x$ with CDF $F(\cdot)$ and

$$y = F(x)$$

$y$ has a uniform distribution between 0 and 1, hence

$$x = F^{-1}(y)$$

• $F(\cdot)$ and $F^{-1}(\cdot)$ are known for Normal and Weibull distribution
Simulating prices

• Simulate multivariate uniform
• Specify Spearman’s rank correlation
• Apply transformation to get correlated random samples from Weibull and Normal distributions
• Add the deterministic component
• Result: prices with desired properties
Simulating merchant interconnectors

- Controllable flow
- Electricity flows from low to high price region
- Feedback into electricity prices
- Calibrated from price effect of NorNed estimated in EPRG 0926
- Price effect scaled proportionally by total demand and interconnector capacity
Simulating merchant interconnectors (cont.)

• Partial equilibrium model
  – Calculate equilibrium prices without constraints
  – Check if transmission constraints are violated
  – If yes: recalculate constrained equilibrium

• Ignore transmission losses (minimal with DC)
• Algorithm calculated numerically on hourly level
• Each simulation generates 8,760 data points
Q1: Can interconnectors between similar markets be profitable?

- Deterministic price properties identical in all three markets
- Correlation in stochastic price shocks of 0.5
Q1: Can interconnectors between similar markets be profitable?

• Benchmark
  – NorNed forecast revenue: €27/MW/h
  – BritNed forecast revenue: €19/MW/h

• Result for identical markets
  – Forecast interconnector revenue: €16/MW/h
Q1: Can interconnectors between similar markets be profitable?

- Deterministic price properties identical in all three markets
- Correlation in stochastic price shocks of 0.5
Simulation results (cont...)

Q1: Can interconnectors between similar markets be profitable?

• Benchmark
  – NorNed forecast revenue: €27/MW/h
  – BritNed forecast revenue: €19/MW/h

• Result
  – Forecast interconnector revenue: €10/MW/h
Simulation results (cont...) 

Q1: Can interconnectors between similar markets be profitable?

• Assumptions
  – €600m for NorNed
  – €384m for BritNed
  – 30 year useful life and no running costs
  – 8% outage rate
Q1: Can interconnectors between similar markets be profitable?

- Internal Rate of Return
  - 29% for NorNed
  - 48% for BritNed

- 3 identical markets calibrated to NL
  - 40% IRR with BritNed cost assumptions
Simulation results (cont...)

Q2: Are fuel price changes important for interconnector revenue?

• NorNed: NL gas price the only feasible driver
  – 40% decrease in NL gas price
  – Average NL and NO electricity prices become equal
  – NorNed revenue falls by 17%
  – NL gas price was <60% of sample average 15% of the time between Jan 06 and Mar 09
Simulation results (cont...)

Q2: Are fuel price changes important for interconnector profits?

• BritNed: GB coal price the only feasible driver
  – 27% increase in GB coal price
  – Average NL and GB electricity prices become equal
  – BritNed revenue falls by <1%
Q3: How do stochastic properties of prices affect interconnector revenue?

![Graph showing the relationship between NL stochastic shock variance and revenue for NorNed and BritNed interconnectors.](source_url)
Q3: How do stochastic properties of prices affect interconnector revenue?

Spearman's rank correlation of stochastic shocks

NorNed
BritNed
Q4: How is increasing wind penetration likely to affect interconnector revenue?

- Greater price volatility due to variable wind
- No empirical work done to measure this
- Calibrated from Green and Vasilakos
  - “Market Behaviour with Large Amounts of Intermittent generation”, *Energy Policy*
  - Results obtained by numerically solving for supply function equilibria
Q5: Can interconnectors mitigate price volatility associated with wind power?

[Graph showing reduction in NL price variance as a function of NL stochastic shock variance relative to baseline. The graph compares the performance of NorNed and NorNed + BritNed.]
Q5: Can interconnectors mitigate price volatility associated with wind power?

- Effect increasing in capacity (actual prices)
Q6: Can interconnectors reduce prices?

- Connect 3 identical markets
  - Price properties and market size as per NL
  - Two 1,000MW interconnectors in line
  - Rank correlation in stochastic shocks at 0.5

- Prices reduced in all 3 markets
  - By around 0.5% in peripheral markets
  - By around 1% in the central market
Q6: Can interconnectors reduce prices?

- Price shocks dampened by arbitrage
- Most volatility accounted for by positive shocks
Q7: How does increasing interconnector capacity affect revenue?

Caution: Linear effect assumed