Evaluating Individual Market Power in Electricity Markets Using Agent-Based Simulation

Fernando Oliveira
fernando@fep.up.pt

A Presentation at the FERC
Washington
January 2004

WHY AGENT-BASED SIMULATION?

It can be used to represent:

- Discrete supply and demand functions
- The detailed internal structure of each firm
- The interaction processes in complex markets:

  a) Analysing the relation between bilateral markets and the balancing mechanism.

  b) Studying the impact of forecasting errors on the efficiency of the industry.

  c) Evaluating the impact of the new market rules on the performance of generators and suppliers.
- The learning processes created by repeated interactions

WHY LEARNING?

- To reflect Bounded-rationality

- To analyse situations where players interact repeatedly

- Consistency with theory (organisations are adaptive systems)

- To approximate solutions in non-linear problems

- To analyse problems in which no equilibrium solution can be computed
    a) There is no equilibrium
    b) There are several equilibria
    c) The problem is computationally too complex!!

Bunn and Day

- Analyse the impact of regulatory divestment, using a computational model, based on the supply function equilibrium.

- They simulate the supply function competition, using:
  - Best response framework
  - Assuming kinked, discontinuous supply functions

- They found no convergence to a unique supply function equilibrium: a cyclic behaviour emerged instead

- They argue that the 1999 divesture of 40% joint capacity of National Power and PowerGen would not be sufficient to completely erode the possibility of market power.

Bower and Bunn

- Look at the switch from uniform to discriminatory pricing.

- They model:
  - Discrete supply functions
  - Different marginal costs for each technology
  - Interactions between players in a repeated game.

- The players use a rule of thumb that balances pricing and generation quantities.

- It does not capture the interaction between the bilateral trading and the balancing market.

- It does not take into account the supply side.

Bunn and Oliveira

- Extends the analysis of Bower and Bunn.
- The simulation platform developed here is a much more detailed representation of how NETA was designed to work:

1. It actively models the demand side (suppliers).

2. It models the interactions between the bilateral market and the balancing mechanism, and the settlement process.

3. It takes into accounts the daily dynamic constraints.

4. It uses learning to allow players to infer a pricing policy.

MOTIVATION AND RESEARCH OBJECTIVES

- In early 2000, Ofgem decided to modify the licenses of the larger generators to include a condition prohibiting abuse of market power.

- Six generators decided to sign the new licence but AES and British Energy refused. The Competition Commission had to resolve this dispute.

- Research question: Do these two apparently small companies have enough “market power” to operate against the public interest?

THE ENGLAND AND WALES GENERATION INDUSTRY

Capacity of each Company (% of Total, 59 GW) in 2000				
	Total	Nuclear	Large Coal+CCGT	Small Coal +OCGT + OIL + Pump. Storage
PG	16.5		17.8	24.9
NP	13.9		14.8	22.5
BE	**12.4**	**58**	**7.1**	
Edison	10.6		9.1	30.7
TXU	9.7		10.5	14.7
AES	**7.8**		**9.2**	**6.8**
EDF	4.7	27.8	1.8	
Magnox	3.9		5.1	
Others	20.5	14.1	24.7	0.4
Total GW	59	7	45	7

THE ENGLAND AND WALES SUPPLY INDUSTRY

Peak Demand 50 GW in 2000				
Market Share of each Company (%)				
London Electricity	12.2		PG	10.2
Eastern	11.2		Scot. & Southern	9.9
NP	10.2		Others	40.7

NETA'S STRUCTURE

1. Forward and Futures Market	3. Balancing Mechanism
Futures and forward contracts	3.5 hours ahead
Years, months, days ahead	The SO accepts offers or bids from generators and suppliers
Generators and suppliers buy and sell	Pay as bid auction
Future and forward prices	
2. Day-Ahead Power Exchanges	**4. Settlement Process**
One day-ahead trading	The SO charges the companies if
Generators and suppliers buy and sell	contract positions <> metered volumes
Power exchange prices	System sell price (SSP)
	System buy price (SBP)

NETA MODEL

For the number of trading days specified

1. Suppliers predict demand for each hour
2. Generators define which plants can run
3. Generators offer in the PX
4. Suppliers bid in the PX
5. Trading in the PX and calculation of System Position in each one of the hours
6. Generators and Suppliers offer (bid) into the BM
7. Trading in the BM and calculation of imbalance prices
8. Settlement Process: calculation of imbalances for each one of the suppliers and generators (plant by plant)
9. Learning

SUPPLIERS AND GENERATORS

- Objectives: To maximise *total daily profits* and to attain their *objectives* for the Balancing Mechanism exposure.

- Instruments: Define the *Mark-ups* for the Power Exchange and for the Balancing Mechanism .

- Each agent uses reinforcement-learning.

GENERATORS' BEHAVIOUR

For each plant in the portfolio:

1. Verify that the objectives for the BM exposure. If they were not achieved, penalise the profit obtained.

2. Given the daily profits in the PX and in the BM revise, for the mark-up used, the:

   2.a) Expected profit in the PX and in the BM.

   2.b) Expected acceptance rate in the PX and in the BM.

3. Define the new offering policy for the next day.

4. In the beginning of the next day. Define the quantities and prices offered for each plant, after knowing which plants are available, making sure that all the operational constraints are respected.

SUPPLIERS' BEHAVIOUR

1. Verify that the objective for the BM exposure was achieved

If not, penalise the profit obtained in the PX.

2. Given the daily profits in the PX and in the BM revise the:

   2.a) Expected profit in the PX and in the BM

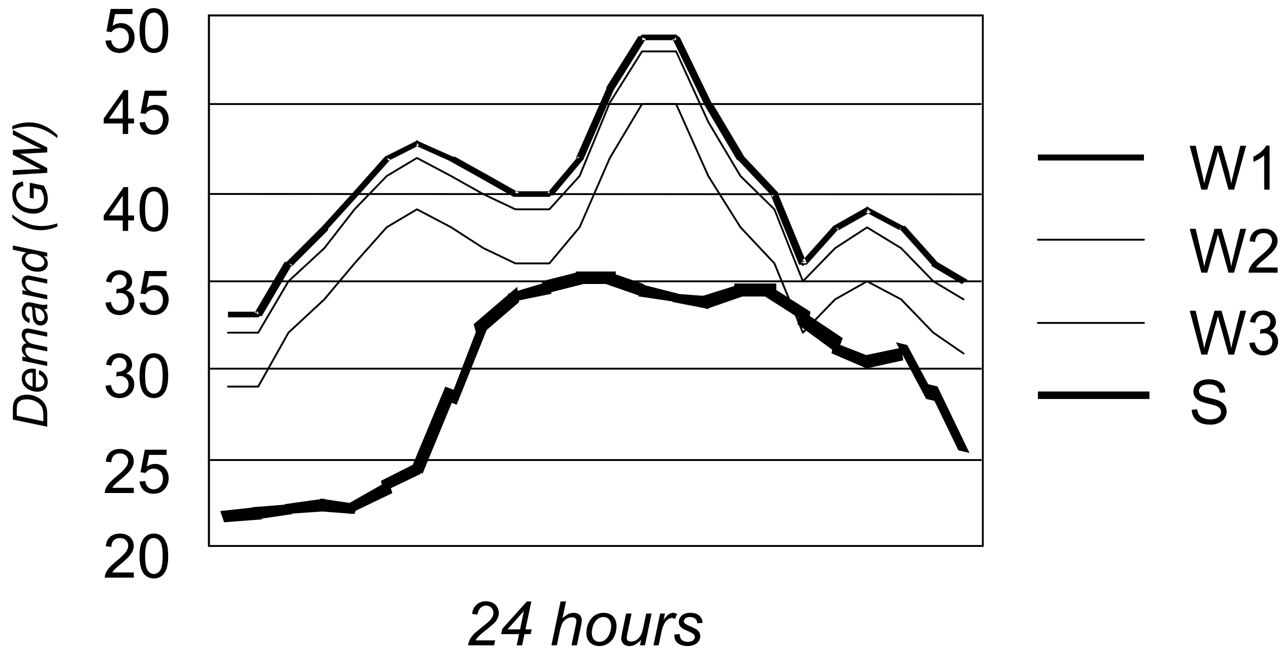
   2.b) Expected acceptance rate in the PX and in the BM

3. Define the new bidding policy for the next day.

4. In the beginning of the next day. After calculating predictions for demand, define the quantities and prices bid.

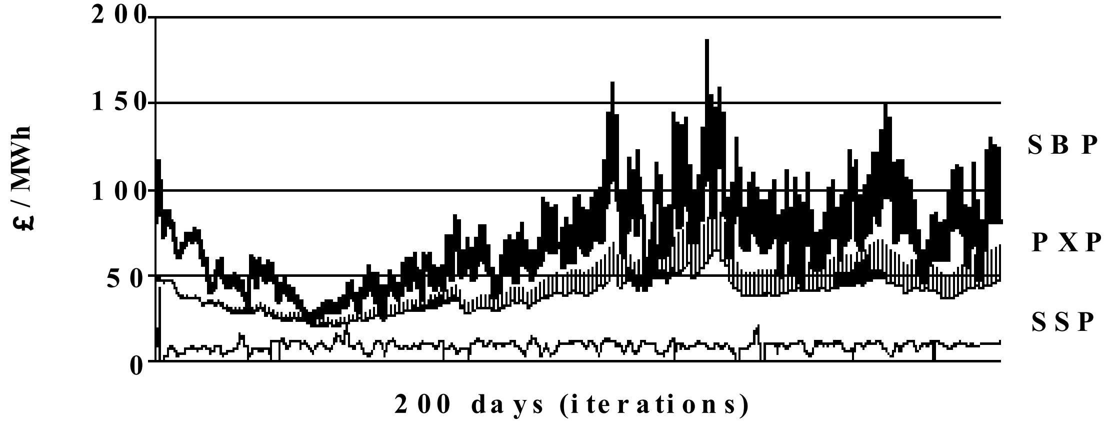
SIMULATIONS

- 80 gensets, owned by 24 Generators
- 13 Suppliers – with 10% demand forecasting error
- 59 GW of capacity in the system
- A peak winter demand of 49 GW, 48 GW and 45 GW
- Summer maintenance outage of 14, 12 and 10 GW



A FIRST ANALYSIS

Average daily prices for the Winter (49 GW) Scenario



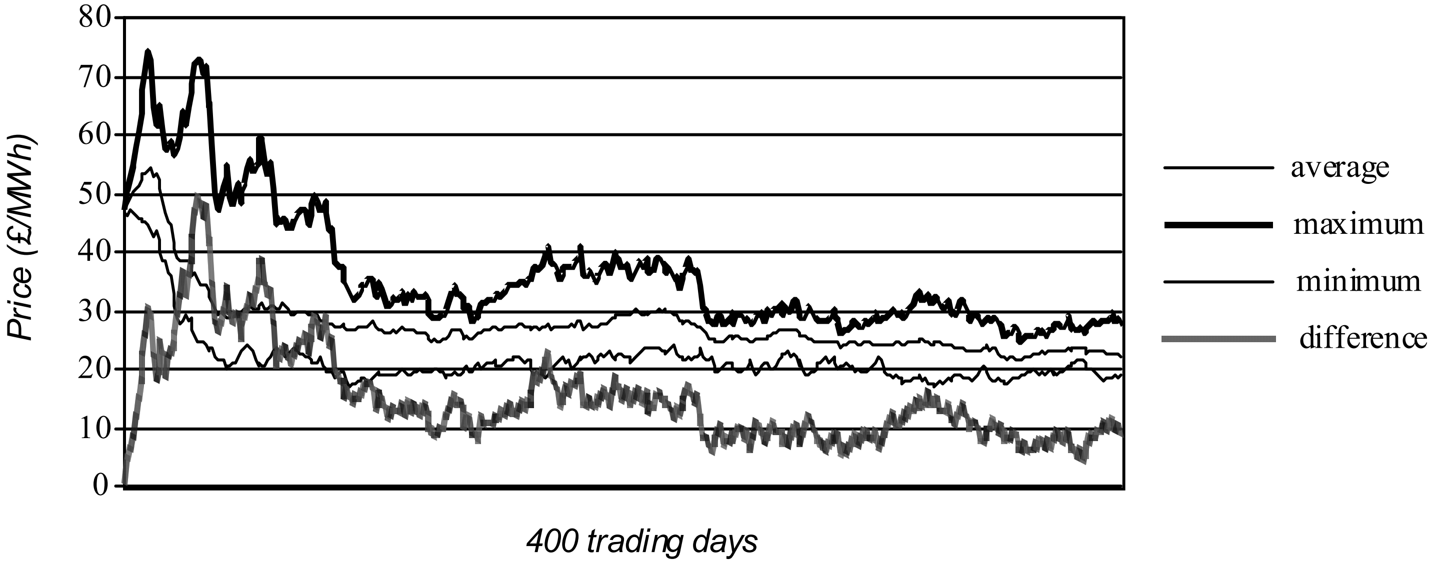
- Less than 80% of capacity used: PXP Marginal costs.

- 80% - 85% of capacity used: PXP > Marginal costs.

- More than 85% of capacity used: PXP seem unbounded

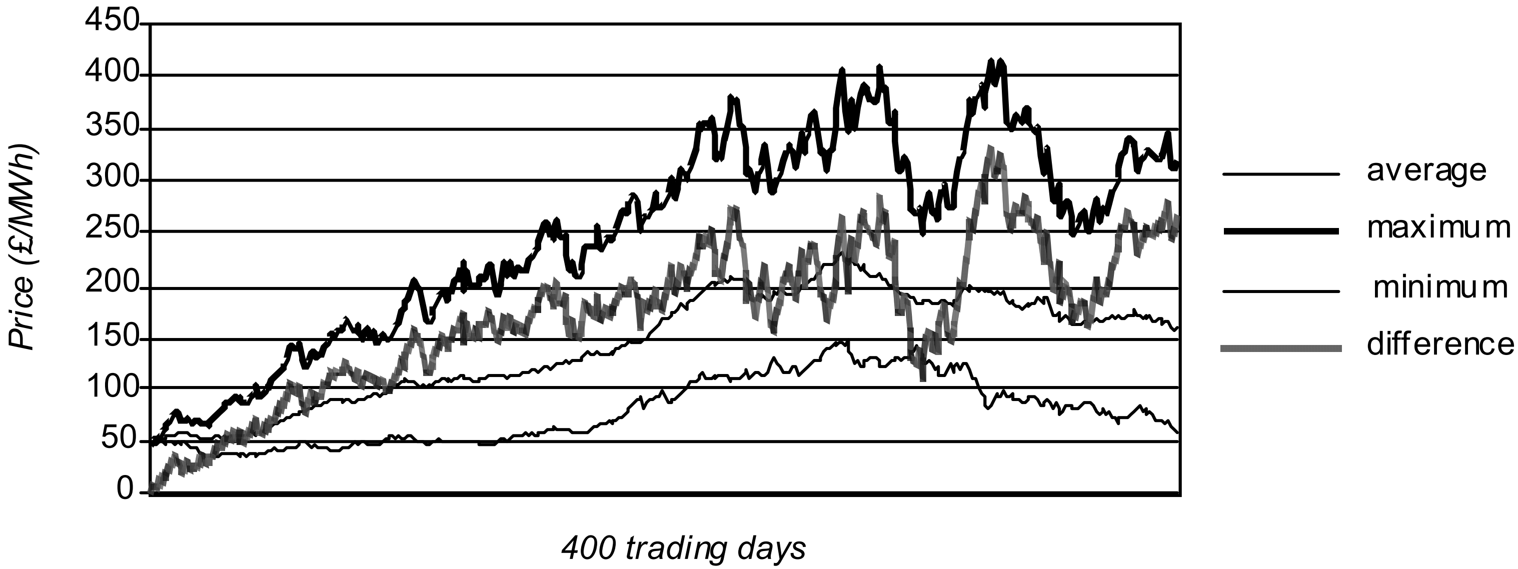
STABILITY AND CONVERGENCE

- A winter day, 10 Simulations, 400 iterations by simulation.
- PXP behaviour (demand 45 GW)



STABILITY AND CONVERGENCE - II

- PXP behaviour (demand 49 GW)



FIRST RESULTS

- The majority of trading (more than 98%) will take place in the bilateral markets.

- Imbalances: much higher than the quantities traded. How high depends on the prediction-errors by suppliers.

- Industry efficiency: will increase if the System Operator publishes predictions more accurate .

FIRST RESULTS - II

• NETA will have ***a greater risk impact on suppliers*** than on generators.

• Generation collusive behaviour is facilitated by low Capacity Margins.

•Suppliers' strategy: ***Demand forecasting is less important than to predict the behaviour of the other suppliers.***

• Agent-based computational learning can provide insights into pricing and strategic behaviour in electricity markets, which was obtained in 2000 just before its introduction in 2001.

AES – BE CASE STUDY: THE STRATEGIES

(ST1) AES and BE act as Bertrand Players with Capacity constraints

(ST2) AES saves capacity for the BM (480 MW)

(ST3) BE saves capacity for the BM (490 MW)

(ST4) AES saves capacity for the BM (480 MW) and closes a Drax genset (645 MW).

(ST5) BE saves capacity for the BM (490 MW) and closes an Eggborough genset (480 MW).

(ST6) Strategies (4) and (5) combined.

AES – BE: RESULTS

- **t-statistics for the PX price (PXP), the SSP and the SBP**

	Strategies				
	ST2	ST3	ST4	ST5	ST6
PXP	1.12	2.21	2.61	2.37	3.55
SSP	0.23	0.83	1.92	0.26	1.7
SBP	-0.15	0.95	0.75	1.98	1.5

- **t-statistics for AES' s and BE' s profits**

	Strategies				
	ST2	ST3	ST4	ST5	ST6
AES	-0.09	1.77	1.31	1.61	2.29
BE	-1.03	0.32	0.58	1.57	3.04

CONCLUSIONS

• BE alone, and BE together with AES, may significantly increase the Price in the Power Exchange and the System Buy Price .

• AES alone cannot influence the wholesale market prices.

• Only when acting together may the firms profit from capacity and prices manipulation.

• The **Competition Commission** concluded that the continuation without modification of the provisions of AES and BE is **not** against the public interest.

DISADVANTAGES OF AGENT-BASED SIMULATION

- Lack of formalism.
- Unjustified assumptions of certain types of behaviour.
- Can easily be modelled to reflect the mental fears and wishes of the modeller, instead of reflecting reality.
- Over-parameterisation and difficult parameterisation.
- Difficult to validate.
- “Impossible” to prove that a model is right.
- A model too complex can be perceived as a “black-box”.
- Causal relationships maybe very difficult to justify, given the decentralised decision process and the more or less complex nature of the system modelled.

ADVANTAGES OF AGENT-BASED SIMULATION

- Lack of formalism.
- Modelling of non-linear systems.
- Detailed description of the systems analysed.
- Capture the learning and adaptation processes within a company.
- Can mimic boundedly rational behaviour: players do not have to optimise.
- Replicate mental models.
- Can look into the future, in a logic way, enabling insights into the nature of complex systems, even in the absence of data.

LANGUAGES AND SOFTWARE

- Visual C++ : Object Oriented, Very Flexible
- JAVA: Object Oriented, Internet Language
- MatLab: Mathematics oriented, fantastic for finance and forecasting; efficiency problem!
- Excel Visual Basic

MODEL DEVELOPMENT

- Oliveira´s Masters in AI: Java
  Development Time: a year

- Bower and Bunn: Excel Visual Basic
  Development Time: a year

- Bunn and Oliveira: MatLab
  Development time: 9 months
    - Design, validation and programming: 6 months
    - Verification and testing: 1 month
    - First experiments: 1 month
    - Data Analysis: 1 month

  Running time: 50 iterations run in 2 hours, Pentium II

ABS LINKS

- Leigh Tesfatsion: Agent-based Computational Economics
  http://www.econ.iastate.edu/tesfatsi/ace.htm
- Gerard Sheble
  http://vulcan.ee.iastate.edu/~sheble/
- MIT ENERGY LAB: Marija Iic
- My website
  http://phd.london.edu/foliveira/