Institution: *London Business School*.

Unit of Assessment: *C19 — Business and Management Studies*.

Title of case study:

Agent-Based Modelling of Electricity Market Behaviour.

1. Summary of the impact

Derek Bunn has led a research programme on understanding competition, market evolution, and prices in electricity markets. He and other researchers in the LBS Energy Markets Group have modelled production facilities in detail, their explicit ownerships, and the price-formation process. Their use of computational learning provides subtle insights which have eluded conventional approaches. The LBS group was the first to do this, and the approach is now widely applied. Relevance of the work is recognised via funding from major energy companies and research organisations. In terms of external impact, *this work has informed extensive advice to several government inquiries, stimulated further research, and is actively used by commericial businesses.*

2. Underpinning research

The case emerges from the LBS Energy Markets Group. This was created in 1986 to provide modelling advice on forecasting and capacity planning to the CEGB, the UK public-sector electricity monopoly. Following the industry's restructuring in 1990, the programme shifted to strategic modelling and pricing behaviour in an oligopolistic industry. It was and is led by Professor Derek Bunn. All work, including the research outputs from 2000–11 listed here, was conducted at LBS.

The liberalisation of the UK electricity sector presented an opportunity to undertake innovative modelling research, and the UK's status in leading the field helped to achieve prominence for the research outputs. The wholesale electricity markets generally have a few large players, and the markets are designed to set distinct prices every hour or half-hour. There is no storage of power and customers do not respond to prices in the short term. Under these circumstances, repeated gaming by the generators is real, rather complex in its dynamics, and very specific to the technological properties of ownership. High price spikes occur from time to time and in the popular press the energy companies are often accused of extracting unreasonably high profits.

Supply-and-demand economic analysis at the market level has not been sufficiently helpful to companies, nor reliable for policy analysis, as such approaches provide incomplete detail. On the other hand, a detailed representation of all of the production facilities, their ownership, and how they interact creates a computational challenge to simulate price formation. The LBS team approached this problem by using computationally intensive, machine-learning techniques. Through a structured trial-and error learning process, simulated within computer models, the interacting agents (real companies) learn to interact and price their assets profitably by reinforcing successful strategies. This approach has its origins in artificial intelligence and co-evolutionary learning.

The results that emerge inform questions on the ability of companies to move the market prices (of interest to competition authorities), how prices and investment might change if the market rules were adjusted (of interest to regulators and policy makers), and how to formulate dynamic pricing strategies (of direct interest to companies). More recently, the agent-focused analysis has been extended by the use of micro-level data for dynamic, empirical analysis of individual bids and offers actually made by market participants, and, in the context of climate change mitigation, to integrate aspects of real options analysis for understanding the propensities of different types of companies to invest in low carbon technologies under various policies.

3. References to the research

"Modeling the Impact of Market Interventions on the Strategic Evolution of Electricity Markets," Derek W. Bunn and Fernando S. Oliveira, *Operations Research* 56(5), September 2008, pp. 1116–1130. DOI: `10.1287/opre.1080.0565`

"Divestiture of Generation Assets in the Electricity Pool of England and Wales: A Computational Approach to Analyzing Market Power," Derek W. Bunn and Christopher J. Day, *Journal of Regulatory Economics* 19(2), March 2001, pp. 123–131. DOI:`10.1023/A:1011141105371`

"Experimental Analysis of the Efficiency of Uniform-Price versus Discriminatory Auctions in the England and Wales Electricity Market," John Bower and Derek K. Bunn, *Journal of Economic Dynamics and Control* 25(3–4), March 2001, pp. 561–592. DOI: `10.1016/S0165-1889(00)00036-1`

"Model-Based Comparisons of Pool and Bilateral Markets for Electricity," John Bower and Derek K. Bunn, *Energy Journal* 21(3), 2000, pp. 1–29.

"Incentives and Coordination in Vertically Related Energy Markets," Augusto Rupérez Micola, Albert Banal-Estañol, and Derek W. Bunn, *Journal of Economic Behavior and Organization* 67(2), August 2008, pp. 381–393. DOI: `10.1016/j.jebo.2006.12.007`

"Crossholdings, Concentration and Information in Capacity-Constrained Sealed Bid-Offer Auctions," Augusto Rupérez Micola and Derek W. Bunn, *Journal of Economic Behavior and Organization* 66(3–4), June 2008, pp. 748–766. DOI: `10.1016/j.jebo.2006.08.003`

"Investment Propensities under Carbon Policy Uncertainty," Janne Kettunen, Derek K. Bunn, and William Blyth, *Energy Journal* 32(1), 2011, pp. 77–117.

Evidence of quality. The journals listed are rated as 2–4⋆ by the Association of Business Schools. Many papers have won prizes. For example, Bunn and Oliveira (2008) won the Prix Academique SYNTEC Conseil en Management 2010, and Bunn and Day (2001) won the Best Paper in Energy at INFORMS Montreal in 1998. The research is well cited; for example over 300 "google cites."

Funding examples. Funding sources since 1998 have included (i) companies seeking to apply the methodology: National Power (now RWEnpower), EdF Energy, GdF Suez, National Grid; (ii) research organisations: KEPRI (Korea) and EPRI (California); (iii) government departments: DEFRA and BIS; and (iv) research funding through EPSRC, ESRC, UKERC and the EU.

4. Details of the impact

Beneficiaries. These include: (i) commercial companies, including energy utilities, who directly employ the methodology; (ii) attendees at courses, advanced workshops, seminars, and conferences organized by the Energy Markets Group; and (iii) regulatory bodies, including the Department of Energy and Climate Change, the Committee on Climate Change, DEFRA, and OFGEM.

Impact channels. Beneficiaries in category (i) are impacted via direct interaction and via custom events; those in category (ii) are impacted via the LBS executive-education programmes; and beneficiaries in category (iii) are impacted via the direct participation of Derek Bunn in policy, by the provision of evidence, and by the use of LBS-produced research by other advisers.

(i) *Direct Impact.* The LBS Energy Markets Group engages in technology transfer. It works with energy utilities to improve competency in the application of techniques derived from its research. The application of the agent-based simulation and econometric techniques are used to model energy and carbon prices, to forecast demand, to optimised risk management, and to understand investment drivers. Four specific examples of such direct impact are described here.

Firstly, in 2013 one of the major European power companies (identity omitted here owing to client confidentiality) implemented agent-based modelling, adapting the algorithms of the LBS approach, into its daily optimisation of trading decisions. Secondly, in 2012 the Electric Power Research Institute (California) worked with the LBS team to incorporate agent-based modelling into the large scale analysis of electricity investment under carbon policies by Centrica and EPRI. Thirdly, in 2009, Centrica funded work aimed at improving their short-term power market modelling. Fourthly, in 2008, the LBS team, led by Bunn, collaborated on the development of an agent-based model for market restructuring by the Korean Electric Power Research Institute.

(ii) *Impact via Energy Markets Group Events.* Courses, advanced workshops, and seminars are offered as both open enrolment and company specific events. Three examples are:

Modelling and Forecasting Energy Prices is an advanced two-day course which gives practical insights into the latest research-based techniques for analysing energy commodity prices.

Modelling and Managing Electricity Markets is a specialised two-day course which gives participants an understanding of the strategic evolution of electricity markets.

Carbon Finance and Analytics is a ten-day programme developed with Point Carbon. It provides a thorough understanding of the evolution and opportunities in climate finance and carbon trading.

London Energy Forum is an annual two-day conference, initially held at the Royal Society.

In all cases these events specifically communicate the research findings and, importantly, the modelling methodology, that are derived as key outputs from the underpinning research project.

Other custom events (usually two-day workshops) also take place at the request of companies that wish to exploit the LBS methodology. Over the 2008–13 window, workshops on techniques for electricity market modelling have been requested by, and delivered at, organisations including

EirGrid (Irish operator), Moody's (utility analysts), OXARA (wind energy developer), Endesa (the largest Spanish and Latin American power company), and EDF (a leading power company).

(iii) *Impact via Regulatory Bodies.* Bunn and his group have carried out policy studies and provided evidence to official enquiries relating to the reform of the electricity market mechanisms; to the interaction of gas, carbon, and electricity markets; and to market structure and market power.

An early impact was in 2000–01 amid concerns about the working of the British electricity market. The LBS work was used by the Competition Commission in its inquiry into market abuse, by Ofgem in its reforms, for the Select Committee on Energy Regulation, and by the National Audit Office.

Ten years later (and within the REF impact window) the electricity market is being reformed again and Bunn is actively involved in research-based advisory roles. Firstly, he has been a specialist advisor to the House of Commons Energy and Climate Change Select Committee: he has briefed MPs prior to their hearings, suggested lines of questioning for witnesses, and advised civil servants in drafting the reports. Secondly, he is an academic advisor to the annual OFGEM Capacity Assessment: this determines the risk of black-outs and so influences policy on the need for investment incentives. Thirdly, we was academic advisor on the setting of official carbon values; these are the internal prices of carbon emissions used across government. Finally, he is regularly used for the quality assessment of models commissioned by the Department for Energy and Climate Change (for example, the Renewable Heat model produced by NERA in 2012).

5. Sources to corroborate the impact

Throughout this section "[link: xxx]" indicates the hyperlink "`tinyurl.com/lbs-ref-emg-xxx`"

1. The ESRC delivered an Impact Report for the 2008–10 award RES-062-23-1052: "Modelling the Evolution of Climate Change Policy ..." which used the methodology of this case study. The report refers to the impact as "outstanding" in various dimensions. A hard copy is available.

2. Sample contact details for those impacted via channel (i) are in the supplementary materials.

3. Links to the LBS open executive-education events:

[link: `forecasting`], [link: `managing`], [link: `carbon`], [link: `carbon-detail`], and [link: `lef2012`].

4. Bunn's role in the Energy and Climate Change Committee is reported at [link: `eccsc-bunn`]

5. The research is cited by the Energy and Climate Change Committee. [link: `debplsv3awe`]

6. For Bunn's involvement with the Department of Energy and Climate Change (DECC) see his review of the DECC 2012 Carbon Values Update [link: `cvsupd`], his research is cited in a DECC Energy Retail Markets Comparability Study [link: `ermcs`] for which Bunn provide a peer review [link: ermcs2], and the assessment (p. 39) for the Renewable Heat Incentive model [link: rhi].

7. The Korean case is reported in *Energy Policy* as DOI: `10.1016/j.enpol.2010.02.049`

8. Sample names and contact email addresses are provided (in the supplement) for corroborators from Ofgem, EPRI, EirGrid, UK Parliament, DECC, and Moody's.