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A Model-Based Comparison of Pool and Bilateral Market Mechanisms for Electricity Trading

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The Revised Electricity Trading Arrangements (RETA), initiated by the Office of Electricity Regulation (OFFER) and Department of Trade and Industry (DTI), proposes that the England & Wales Electricity Pool be replaced by bilateral trading ("the bilateral model"). This will allow direct contracting between counterparties, paying generators what they bid, and introducing an optional balancing market. Underlying the proposed reforms is the strong belief that changing the trading arrangements will limit the potential for the exploitation of market power by generators, whilst still providing a favourable operating environment for flexible coal plant, and result in wholesale electricity prices falling by around 10%. Until now, there has been little quantitative analysis of the RETA proposals and they have progressed with a surprising degree consensus on both sides of the market. In this study, we have therefore developed a computer simulation model of the wholesale electricity market in England & Wales as a means of systematically testing the potential impact of alternative trading arrangements on market prices. Generating firms are represented as autonomous "adaptive agents", which progressively learn to adopt profit maximising bidding behaviour. Unlike conventional simulation models, where agent behaviour is imposed exogenously by the modeller, elements of artificial intelligence are included to allow agents to independently develop their own trading strategies. Agents compete with each other in a repeated daily auction market setting where we test four different combinations of bidding and settlement rules. The results show that daily bidding with Pay SMP settlement, as in the current Pool day-ahead market, produces the lowest prices while hourly bidding with Pay Bid settlement, as proposed in the new bilateral model, produces the highest prices. This occurs, firstly, because hourly bidding allows generators to more effectively segment the market between on-peak and off-peak hours hence allowing more of the consumer surplus to be extracted and making tacit collusion easier. Secondly, it appears that Pay Bid increases the potential for over-bidding by baseload generators, particularly independent power producers with small plant portfolios, reducing competitive pressure on generators with mid-merit plant. These results suggest that the bilateral model could amplify existing mid-merit generator market power and lead to relatively higher prices than the pool model, precisely the opposite of what OFFER, the DTI, and consumer groups are hoping for. However, OFFER is introducing RETA at the same time as forcing further divestment of plant by mid-merit generators. New entrants continue to add capacity, and full liberalisation of the retail market is beginning to increase competition among suppliers. It is therefore possible that market prices could still fall, despite RETA, but, in retrospect, it will be difficult to identify which changes have had a beneficial effect. Moreover, some aspects of the RETA proposal could even be beneficial, such as a firm day-ahead market, a balancing market that better allocates costs and risks, and the abolishment of capacity and availability payments. The virtue of using a modelling approach is that it has allowed us to focus on one set of changes, namely the reform of market clearing and settlement arrangements, while holding all else constant. It is on this basis that we argue that the bilateral model, as proposed, is likely to have a detrimental effect even though other reforms going on at the same time, particularly of the industry structure, could lead to the market as whole becoming more efficient.

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1. Introduction

The Office of Electricity Regulation (OFFER) launched the industry-wide *Review of Electricity Trading Arrangements* in November 1997. This involved industrial and domestic consumer groups, fuel suppliers, researchers, consultants, several government departments, and the Pool Executive Committee (see Electricity Pool of England and Wales, 1997, Offer, 1997b, and Offer, 1998a-j, for consultation documents). The review was part of a wider UK energy policy debate, and can be broadly characterised as serving three constituencies:

i) Consumer groups, who believed that the Pool's trading arrangements were contributing to generator market power and high prices;
ii) OFFER, who wanted to create a more competitive industry and greater synergy with the gas market; and
iii) Government, which was concerned about fuel diversity and security, and wanted to prevent excessive investment in gas-fired generation capacity at the expense of coal.

The primary driver for change, at least from the consumers' point of view, is the desire to see lower prices in the wholesale electricity market. OFFER clearly shared these concerns and noted that, on a time weighted basis, the average winter Pool price in 1997/98 was 12% higher, in real terms, than in the previous year, and 35% higher than in winter 1990/91 (see Figure 1) when the Pool began trading (Offer, 1998k). More recently, the regulator explicitly stated that "Pool prices must come down" (Offer 1999a) and estimated that gaming in the Pool had raised SMP by an estimated £90m, in December 1998, as compared to 1996 and 1997 (Offer 1999b). Furthermore, there has always been a strong suspicion, particularly from consumer groups, that the market mechanism, embodied in the current Pool trading arrangements, might be creating or at least contributing to generator market power in the Pool. Changing the Pool trading arrangements, in their view, was therefore an essential prerequisite for reducing market prices. However, in the past, OFFER has been less convinced and when the whole issue of Pool trading arrangements was last reviewed (Offer, 1994a) it found there was insufficient evidence to instigate further reform. The main conclusion was that a Pay SMP mechanism, where generators are paid in a *uniform* fashion with the System Marginal Price, offered some economic advantages over a Pay Bid mechanism, where generators are paid in a *discriminatory* fashion with their own bid price. It is therefore only recently that OFFER has been persuaded that a change in the Pool price mechanism might reduce market power, and the rationale for this switch in opinion remains an open question.

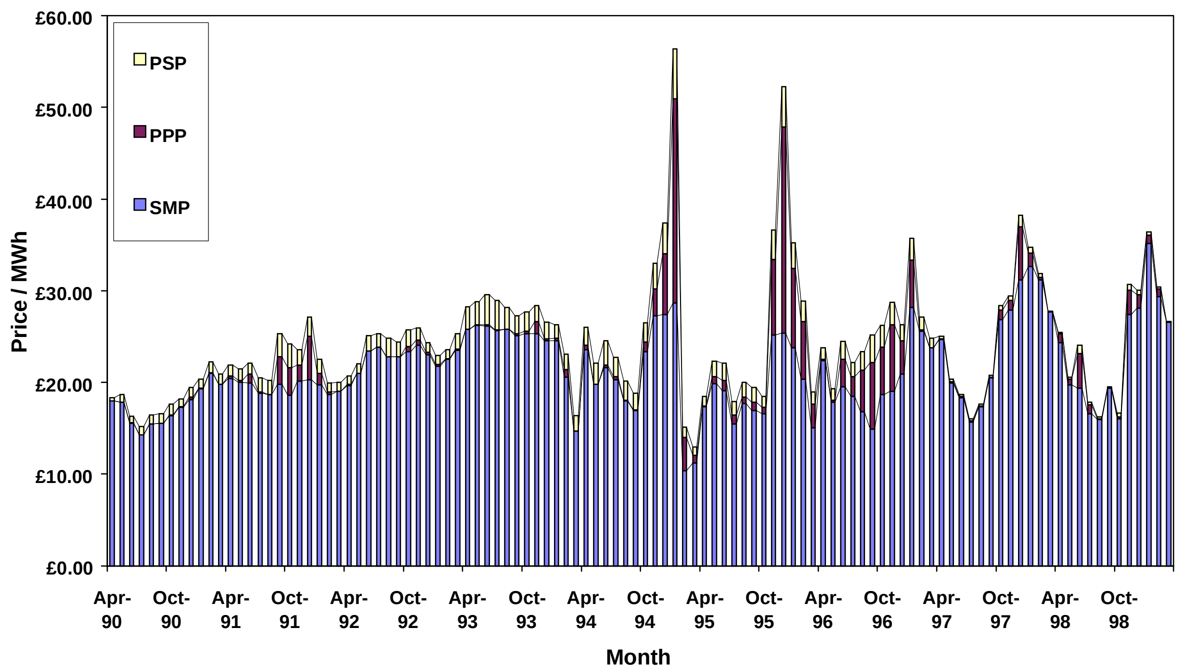
For OFFER, increasing competition has been a major objective. However, creating an attractive environment for new entrants, at the same time as keeping a lid on prices, has resulted in a constant series of reviews, and interventions. The most significant of these has been the two year cap on Pool prices during 1994-96 in which the two largest fossil fuel generators, National Power and PowerGen, agreed to bid in such a way as to keep the annual average Pool prices below £24/Mwh. The lifting of this cap was contingent upon the divestment of 4,000 MW and 2,000 MW of capacity by National Power and PowerGen, respectively, both of which was taken up by Eastern Electricity (Offer, 1994b)[1], a Regional Electricity Company (REC)[2]. The review of trading arrangements has therefore given OFFER a new opportunity to re-open the debate on curtailing the market power of National Power and PowerGen, through further divestment, and agreement has been reached that each company will sell approximately 4,000 MW of additional capacity during 1999.

Whilst OFFER and consumer groups were focusing on the problem of market power, and high prices, the Government became increasingly concerned with the demise of coal and the growing dependence of the UK on natural gas as the primary fuel source for electricity generation. Indeed, so great was its concern is that in December 1997 the Department of Trade and Industry (DTI) announced it had placed a moratorium on the granting any new licences, so called Section 36 and Section 14 consent, for the building of additional combined cycle gas turbine (CCGT) plant. However, the Government was not able to revoke those licences already granted and, if all of these planned CCGT plants are eventually built, natural gas would account for 40% of total generation capacity in England and Wales. This "dash for gas" has been driven by a high Pool price, which averaged £25.96/MWh in 1997/98, a fall of 60% in the avoidable cost of CCGT generation, since 1990, to around £8/MWh, and a 25% reduction in the capital cost of building new CCGT plant. With a

[1] Eastern leased the plants, rather than buying them outright, and pays approximately £6/MWh for each MW generated. This means National Power and PowerGen still benefit from the output of these plants.
[2] Previously, OFFER and UK competition authorities had resisted attempts to vertically reintegrate the industry by preventing RECs from owning significant amounts of generating capacity.

construction time of less than two years, for new CCGT plant, it is no surprise that natural gas has become the fuel of choice for new entrants and incumbent generators.

Figure 1. Monthly time weighted average Pool prices



Many argue that this whole phenomenon would not have come about if the wholesale market been more balanced and prices had been lower. The Government clearly sees a link between these issues and when it published the conclusions of its inquiry into fuel sources for power stations (DTI,1997,1998b) it proposed continuing the moratorium on licensing new CCGT plant, until Pool trading arrangements had been reformed, and plant divestment had taken place. In its Green Paper on utility regulation (DTI, 1998a) the Government also proposed that OFFER's primary duty should be to protect customers', short, medium, and long term interests. In this respect, it is likely that OFFER and the DTI will, in future, intervene more directly in the way that the market is governed and organised.

Clearly, OFFER and the Government are attempting to resolve a number of complex, and interrelated, issues which are difficult to address in an analytically tractable way using conventional economic models of imperfect competition, and are too idiosyncratic to appeal to experiences elsewhere. We have therefore turned to a simulation model based approach in order to test the impact of a range of different trading arrangements on generator bidding strategies, and hence on market prices. Before describing the simulation model, we summarise the RETA bilateral trading proposal, highlighting the essential differences with the current Pool, and review the literature on auction theory insofar as it gives comparative insights.

2. The Pool and bilateral mechanisms

OFFER (1998i, Ch 4) identified the following major weaknesses in the current Pool trading arrangements:

i. price setting in the Pool is overly complex, for example, it requires the submission of at least nine different bid parameters for each genset and requires a rule book, of over six hundred pages, to describe the price calculation methodology;

ii. capacity and availability payments reward generators for making plant available, not operating it, and it has limited value as a price signal to generation or demand side of the market to respond to short-term changes in market conditions;

iii. bids do not reflect costs as many baseload generators consistently bid a zero price, so called zero-zero bids, relying on the mid-merit generators to set SMP;

iv. prices have risen substantially, and become increasingly volatile, since the Pool began trading even though fossil fuel prices have all fallen;
v. market liquidity, and the lack of publicly available price data, puts consumers at a disadvantage when negotiating forward contract cover against Pool prices;
vi. non-firm nature of the day-ahead market transfers costs and risks of plant failures, from generators to customers, through Energy Uplift payments;
vii. the security of electricity supply is being threatened because generators can sign cheap 'interruptible' gas supply contracts, or sell gas from 'firm' gas supply contracts when spot gas prices rise, without paying a corresponding penalty in the electricity market; and
viii. the participation of the demand side in price setting is limited to a few very large industrial consumers.

Consumer groups have generally echoed these concerns in their submissions to the previous (Offer, 1994a) and the current reviews of pool trading arrangements. Outside commentators have also made similar criticisms (Newbery, 1997; Offer, 1998f; Offer, 1998g) some of whom have proposed a number of alternative models, which OFFER synthesised into an interim "common model" (Offer, 1998h) and eventually the bilateral model (Offer 1998j). The proposal seeks to address the weaknesses listed above by essentially adopting trading arrangements mimicking those in traditional commodity markets. These include:

i. simplifying generator's bids so that they are only for a given price, quantity, and delivery period which means that generators must internalise all the associated costs of start-up and fixed costs of operating a plant;
ii. eliminating capacity and availability payments;
iii. forcing all generators and consumers to compete more actively in setting market prices by introducing Pay Bid pricing;
iv. introducing screen-based trading, in the short-term and balancing markets, to promote real-time price transparency and encourage independent price reporting as in other commodity futures markets;
v. making all bids and offers 'firm' which means that a generator must deliver, and a consumer take delivery, against their contracted positions or face the uncertain consequences of the Independent System Operator (ISO) buying or selling in the balancing market, on their behalf, and passing the costs back to them;
vi. imposing the full cost and risk of interruptible gas contracts and firm gas sales, back on the generators, by allowing the ISO buy-in any under-delivery against notified contract positions; and
vii. exposing large consumers to the full impact of price risk in the balancing market, hence, forcing them to take responsibility for matching their contracted purchases to their expected demand, and giving them an incentive to undertake more active load management.

The proposed bilateral model has the following key components; i.) a voluntary forward market as required by consumers and generators, ii) a voluntary, screen-based, short-term market, operating from at least 24 hours to 4 hours before despatch, which will trade half hourly blocks of power, iii) a voluntary, screen-based, half hourly balancing market, operating from 4 hours before despatch right through the particular half hour despatch period in question, iv) a mandatory settlement process for imbalances. Under this arrangement, generators and consumers who have contracted for physical deliveries of electricity, through the forward or short-term market, will be responsible for self-despatching those contracts. Their only other responsibility will be to notify their contract positions to the ISO by the time that the short-term market closes ("gate closure") some four hours before despatch. After this point, the ISO will assume full responsibility for any further contracting necessary to maintain system security until despatch is completed. This will be achieved by buying and selling in the balancing market to cover any imbalances between notified contracted positions and actual demand and supply. In addition, the ISO will continue to buy in ancillary services, under a tendering system similar to that which is now used for procuring reactive power, frequency response, and black-start capabilities. At the moment, the ISO function is likely to continue to be performed by the National Grid Company (NGC).

Though OFFER sees the bilateral model operating in three distinct markets, performing three distinct functions, it could just as easily operate with only the forward and the balancing market. In particular, some generators and consumers may choose to use the balancing market like a traditional spot commodity market, where residual uncontracted power is offered alongside bids for increments and decrements from contracted positions. This is almost certain to be the case for high cost plant, which is capable of providing load following capabilities or peak lopping at short notice, but which will not be able to compete with baseload or mid-merit plant in the forward market. However, the experience of other commodity markets, and electricity markets that use bilateral trading arrangements, is that usually only about 1-2% of total trading is done in the spot market. As for the short-term market, which is nothing more than a one day screen-based futures market, it might develop into a fully functioning electricity futures market[3] as OFFER hopes. However, it is equally likely that, that generators and consumers may simply ignore it and indeed some have already indicated their preference for continuing to trade in a forward market similar to the current CFD and EFA markets. Unless the short-term market can provide additional liquidity, or lower transaction costs, it seems likely that it will simply become part of the forward market rather than a separate market in its own right.

3. Theoretical insights

In terms of formal auction theory, the Pool's day-ahead market is classified as a *uniform-price auction* because successful bidders all receive the same price for multiple units of output, with the price being equal to the highest (marginal) bid price accepted. In contrast, the bilateral model's short-term market is a *discriminatory auction* with successful bidders receiving price(s) for each unit of out put equal to the price(s) they actually bid. Studies by Simon (1994) and Nyborg & Sundaresan (1996) compared uniform-price auction and discriminatory auctions directly by analysing the market for US treasury bills. They analysed yields on these instruments from the period before, and after, the US Treasury transformed the market from a discriminatory auction to a uniform price auction but found no significant difference in the prices that resulted under the two different sets of trading arrangements. This analysis is particularly important because the US treasury bill market has many similarities with the wholesale electricity market in England & Wales in that both are regularly repeated auctions and both have an important forward market element running alongside the physical delivery auction. The conclusion that they drew was that the forward market significantly contributed to the dissemination of information between potential bidders and helped relieve information asymmetries which would otherwise lead to market inefficiencies, hence the equivalence of prices seen under the two types of auction mechanism. Given the close analogy with the two types of US treasury auction described above, it is tempting to conclude that there would also be no real difference between the Pool and bilateral model. However, this would ignore the fact that there is a clear lack of liquidity and transparency in the CFD and EFA markets which means that the process of price discovery is significantly less effective than in the treasury market. Moreover, in both types of treasury auction the bidders made simultaneous sealed bids, a rule applying in the Pool but not necessarily to the bilateral model if prices are indeed posted on a screen-based trading system. In the bilateral model, as envisaged, bids will therefore be made progressively. However, if bidders choose to avoid posting their prices publicly then there may be even less information available than in the current Pool day-ahead market. Finally, there are around forty bidders in the US treasury bill market, none with a dominant market share, which makes it significantly more difficult for any one bidder or group of bidders to maintain price discipline.

Rothkopf (1997) highlights the central importance of repetition in electricity auctions, a fact that has often ignored in traditional auction theory, and stresses the fact that tacit collusion a is much greater problem when bidders meet repeatedly whichever auction method is chosen. He cites laboratory experiments by Isaac &Walker (1985) where subjects are allowed to discuss and coordinate bidding strategies, over many different auction types including multi-unit auctions, which resulted in a significant level of collusion in many cases. To combat these implicit and explicit collusion problems, he suggests that delaying the release of information about bids and auction outcomes, particularly from sealed bid auctions like the Pool, and stresses the need for effectively enforced prohibitions on active conspiracy between bidders. However, delaying information is at variance with increasing information availability to increase efficiency and cannot provide a complete solution. The conclusion he draws about electricity trading arrangements in California is that a sealed bid auction is better than a progressive auction but that to avoid collusion care must be taken in deciding which information to release. In this respect, it is interesting to note that considerably more information is now released about generators' bids in the Pool than when it first began trading. It is also interesting to speculate as to whether the increase in prices since the Pool began trading might have any correlation with this increase in the availability of information.

[3] The short-term market may eventually evolve into a futures market, trading longer term electricity contracts like, for example, the four electricity futures (and associated options) contracts which are traded on the New York Mercantile Exchange (NYMEX).

Auctions are addressed from a sociological rather than economic perspective by Smith (1990) suggesting that bidders should be thought of as social groups with norms, values and behavioural rules. He provides empirical evidence from New York jewellery auctions where regularly repeated auctions are attended by an essentially closed group of bidders who have come to clear understandings about how and when they will compete for particular lots on offer. These result in bids, and hence prices, which fit with the group's notion of "worth" not the truly competitive reservation price predicted by auction theory. The importance of behavioural learning, through repetition, in auctions is further illustrated in experiments carried out by Cox, Smith & Walker, (1984). These show that subjects often do not follow the dominant bidding strategy, to begin with, but gradually learn to adopt the strategy over time as their experience increases through repetition.

Collusive behaviour stemming from the repetitive nature of daily Pool bidding is not the only reason why prices might be higher than those expected in a perfectly competitive market. In her empirical analysis of the strategic bidding behaviour of generators in the Pool, Wolfram (1997) finds evidence that strategic bid increases are indeed occurring and that this is particularly prevalent for bidders with large portfolios of plant. They tend to bid higher than other bidders, all else equal, because they receive a larger payoff on all their lower price units, have the necessary spare capacity, and biggest incentive to bid in such a way as to raise the marginal price setting bid. This is also consistent with the findings of Bunn, Day & Vlahos (1998) that, even in the absence of collusion, generators could still exercise market power in the current Pool. The importance of generators' ability to influence the marginal bid price was also investigated in the early days of the Pool by von der Fehr (1991) who believed that even a small changes to the institutional set-up of the Pool could make a significant difference to the final market price. Using a game theoretic approach, he showed that if the Pool was modified so that the second highest bid, rather than the highest, was used to set the uniform price then this would immediately remove the ability of firms to influence it and make marginal cost bidding a dominant strategy.

The general conclusion we draw from the limited literature available on multi-unit, multi-period, auctions is that where bidders are not symmetric and have market power, large generators can and do actively seek to influence the marginal market price to keep prices well above marginal cost. The opportunity for generators to learn about each other's bidding behaviour, and adapt their bidding strategies accordingly, is also clearly offered by the daily repetition of the day-ahead market, and by the provision of extensive bid information. However, though the literature contains some useful examples of empirical and experimental analysis of uniform price and discriminatory auctions, none are completely analogous to the Pool or bilateral model. Therefore, from the point of view of the electricity market in England & Wales it provides no concrete evidence, either way, as to which auction type(s) would produce the lowest market price.

4. Modelling the Pool and bilateral model

We have developed an *agent-based simulation* (ABS) model of the wholesale market for electricity market in England & Wales which allows us to compare market prices, and the bidding strategies of individual generators under the different trading arrangements. The key feature of this simulation approach is that it uses a micro-level, bottom-up, representation of the market with each generating firm represented, at the level of its individual power plants, by a separate computer generated *autonomous adaptive agent* ("agent"). The agents are capable of developing their own bidding strategies, to explore and exploit the capacity and technical constraints of plant, market demand, and different market clearing and settlement arrangements. In other words, the model provides us with an experimental platform on which to test the impact of changing the essential elements of the current Pool trading arrangements with alternatives such as those proposed in the bilateral model.

4.1. Modelling objective

The crucial focus of comparison is the Pool's day-ahead market versus the bilateral short-term market. We model both as a daily repeated auction and compare the market clearing prices set under the four different combinations of trading, and settlement, arrangements set out in Table 1.

Clearly these are stylised models, ignoring much of the complexity of the real Pool day-ahead and bilateral short-term markets but they allow us to isolate the following key issues:

i) Pay SMP versus Pay Bid settlement;
ii) daily bids versus hourly bids;
iii) learning through repetition; and
iv) impact of information availability.

Table 1. Alternative auction models tested

Market	Bidding	Settlement
1. Pool day-ahead	Daily	Uniform Price (Pay SMP)
2. Pool day-ahead	Daily	Discriminatory (Pay Bid)
3. Bilateral short-term	Hourly	Uniform Price (Pay SMP)
4. Bilateral short-term	Hourly	Discriminatory (Pay Bid)

4.2. Modelling architecture

The ABS model we have developed has a trading environment, a set of agents, and an economic environment. The trading environment is a daily repeated auction upon which different combinations of bidding, clearing and settlement arrangements, described above, are exogenously imposed along with any regulatory controls on allowed agent bidding behaviour. Each agent represents one of the generating firms operating in the Pool during 1998, and which is endowed with a portfolio of plants characterised by capacity, fuel type, efficiency, availability, etc. The economic environment defines the demand pattern for electricity, and the input costs, both of which are imposed exogenously as static variables.

4.2.1. The trading environment

At the start of each simulated trading day, each agent is allowed to submit one bid for each plant in its portfolio and we assume that all the expected available capacity makes a 'firm' bid for the whole day. Each bid is therefore linked to a specific plant capacity, which means that agents are, in effect, submitting firm bid supply functions. This is consistent with the work of Klemper and Myer (1989), later used by Green and Newbery (1992) and Green (1996) in their analysis of the bidding behaviour of generators in the Pool.

Bidding is allowed in one of two ways, either a single price for each plant for a whole day (daily bids) as in the current Pool's day-ahead market, or 24 separate hourly prices for each plant (hourly bids) as in the bilateral model's short-term market. The market is cleared by stacking the plant bids, low to high, and allocating demand to plants, in strict merit order, until demand is exhausted for each hourly period. There are therefore 24 separate hourly settlement prices in each trading day, and any plant that has bid above the bid price of the marginal plant in any given hour has a zero utilisation rate. The auction results are simultaneously calculated, for all 24 hours, at the end of the trading day. Revenues are calculated on the basis of demand allocated multiplied by the price bid by the marginal plant in each hour (Pay SMP settlement), or on the basis of a plants own bid (Pay Bid settlement). All agents simultaneously receive the results of their bids at the end of the trading day, and even where separate hourly bids are submitted there is no opportunity to observe the outcome of these until trading is completed.

Recently OFFER have suggested that transitional arrangements be put in place before the bilateral model is introduced which would simplify the current Pool's day-ahead bidding process by allowing only one daily bid per genset (Offer 1999c). The model we have developed here reflects this proposal in that only one bid is allowed per plant, per day, although we have avoided the complexity of attempting to model individual genset bids within plants.

4.2.2. The agents

The agents, summarised in Appendix A., represent the different generating firms, and centrally despatched plant capacities, marginal production costs, and expected plant availabilities, during 1998. These were synthesised from a range of public, and private, sources as well as our own estimates.

The ABS approach allows us to avoid making the usual restrictive assumptions that are required by traditional economic analysis of imperfect competition. Instead, the agents use simple internal decision rules, summarised in Table 2., that allow them to 'discover' and 'learn' strategic solutions which satisfy their profit and market share objectives over time. Taken together, these rules constitute what is essentially a naïve reinforcement learning algorithm[4] that seeks out and exploits successful bidding strategies while discarding unsuccessful bidding strategies. As a result, the behaviour of the simulated market is almost entirely emergent as it is created endogenously by the aggregate interaction between agents and their environment.

Table 2. Summary of agent bidding rules and objectives

Rule 1. Self awareness
Agents receive feedback data from their own trading activities for the previous two trading days': i. Plant avoidable costs of production; ii. Plant bid prices; iii. Plant sales prices; iv. Plant and total portfolio expected available capacity; v. Plant and total portfolio sales volume; vi. Plant and portfolio rate of utilisation; vii. Plant and portfolio profit; viii. Portfolio target utilisation; ix. Portfolio target profit.
Rule 2: Information restrictions
Agents do not know the past, current, or future, actions of other agents or the state of the market.
Rule 3: Objective functions
Agents have common objectives for each new trading day which are to achieve : i. at least their target rate of utilisation for their whole plant portfolio; and ii. a higher profit on their own plant portfolio, than for the previous trading day.
Rule 4: Strategy selection
Agents submit bid price(s) for each plant in their portfolio, at the beginning of the current trading day, using decision criteria in the following order of precedence: i. if the target rate of utilisation was not reached across the portfolio, on the previous trading day, then randomly subtract a percentage from the previous day's bid price for each plant in the portfolio; ii. if any plant sold output for a lower price than other plants across the portfolio, on previous trading day, then raise the bid price of that plant to the next highest bid price submitted; iii. if total profit did not increase across the portfolio, on the previous trading day, then randomly add or subtract a percentage from the previous day's bid price for each plant in the portfolio; and iv. if profit and utilisation objectives were achieved across the portfolio, on the previous trading day, then repeat the previous trading day's decision.
Rule 5. Strategy restrictions
Agents can follow any strategy on condition that the bid prices in their plant portfolio are always: i. no less than £0.00; ii. no more than £1000.00; iii. rounded to two decimal places; and iv. higher for high marginal production cost plant than for low marginal production cost plant in the portfolio.

The agents' bidding strategies are therefore not specified exogenously by the modeller but are developed by the agents themselves. The model also has the advantage of allowing bidding strategies to be observed for asymmetric bidders, right down to the individual plant level. ABS is therefore a distinctly bottom-up approach

[4] See Sutton and Barto, (1998) for a definition and fuller discussion of the many different forms of reinforcement learning which have been developed.

focussing on individual strategic decision making behaviour, rather than top-down aggregate market behaviour.

Strategic learning is driven by each agent attempting to jointly satisfy the two objectives of:

i) continuously increasing its own overall profitability, from one period to the next; and
ii) reaching a target utilisation rate on its plant portfolio in every period.

To reach these objectives, agents may follow either a 'price raising' strategy, by adding a random percentage to the bid(s) they submitted in the previous trading day or a 'price lowering' strategy, by subtracting a random percentage[5]. The agents may raise or lower bid prices to any level, between zero and £1000.00, but plants with high marginal costs of production must always bid higher prices than plants, in the same portfolio, with lower costs of production. To replicate the impact of forward contract cover, we assume that forward contracting reflects each generator's desire to guarantee itself a minimum level of market share, or output, in a given period. For each agent we have therefore estimated a minimum target rate of utilisation for its plants, expressed as a percentage of expected total available MWh of capacity across its whole portfolio. From the point of view of the simulation, if an agent failed to reach its target utilisation rate on the previous trading day, then it lowers the bid price(s) on all of its plants for the current trading day. Though this response disregards the potential impact on profitability, and the success of previous strategies, the target utilisation rate is attached to an agent's portfolio, not to particular plant(s), so they are still free to explore a wide range of bidding strategies which will satisfy both profit and utilisation objectives. Finally, an agent can transfer a successful bidding strategy, from one of its plants, to all other plants in its portfolio. This favours agents with large plant portfolios as they naturally have more opportunities to experiment with, identify and adopt successful bidding strategies than a single plant operator. This is achieved by allowing agents to automatically raise the bid price on any plant, to the level of the next highest bid price submitted, if it sold its output for less the marginal sales price achieved in the portfolio on the previous trading day.

In practice each agent is continuously updating its profit objective, as the simulation progresses, always using the previous trading day's profit as a benchmark against which it compares the current day's profits. By continuously updating their profit objective, at the end of each trading period, agents are forced to continuously compete against each other. As in the real world, not all the agents can increase their profits indefinitely and, at some point, a profit increase by one agent will cause a profit decrease for another agent. When an agent suffers a profit decrease it is prompted to abandon its current bidding strategy and randomly look for a more successful one. When it eventually finds a better strategy, which might mean taking profit from another agent, this would trigger a new strategy search by the affected agent, and so on.

A criticism of the proposed bilateral model is that less information will be available to participants than is currently available in the Pool, especially if generators refuse to participate in the short-term market. We have eliminated this potential informational difference in our model so that we can focus purely on the impact of alternative bidding and settlement arrangements. We do this by assuming that agents know everything about their own portfolio of plants, bids, output levels, and profits, but nothing about other agents or the state of the market. Their ability to capture and retain data is very limited, they have no powers of strategic reasoning, and hence they exhibit a high degree of bounded rationality.

4.2.3. The economic environment

In contrast to the supply side of the market, we assume that all the agents on the demand side are price takers with no ability to influence the market through strategic behaviour. For simplicity, we therefore model them as an aggregate demand curve. To simplify the analysis, we have created a standardised daily load profile, corresponding to the demand patterns seen on a typical winter day.

We know that demand response to increasing prices is very low in the Pool day-ahead market, which is one of the major criticisms of it, because of the limited amount of demand-side bidding that occurs. Typically, about 750 MW of demand side bids are usually submitted between £80/MWh and 250/MWh and NGC studies show a further 2,000MW of active demand management occurring under schemes run by RECs. An uncertain

[5] In all the simulations discussed here, agents draw their random percentage values from a uniform distribution with a range +/- 10% and a mean of 0% though we have tested other distributions with little apparent effect.

amount of private load management also occurs, which we assume accounts for another 2,000 MW of demand response, which is also likely to be from industrial customers. For the purposes of our simulations, we have therefore assumed a linear load shedding response of 25 MW for every £1MWh that SMP rises above £75/MWh. Therefore at a SMP of £175/MWh we are assuming that a total of 2,500 MW of demand side response occurs. Our estimate of short-term demand side elasticity is much lower than that used by Green (1992), who assumed a load drop of 500 MW per £1/MWh. However, it is quite close to the empirical estimates of Patrick and Wolack (1997) who calculate elasticities of between -.1 and -.3 for large industrial customers which, given that they contribute about 15,000 MW of demand in the Pool, would be very roughly equivalent to a load drop of 15 - 45 MW per £1/MWh at peak on typical winter day. Appendix B shows the standardised daily load profile as it would be at prices between £75/MWh and £300/MWh MWh.

5. Simulation results

In this section we describe and discuss the results of our simulations for different trading arrangements but first we describe the simulation conditions and assumptions

5.1. Simulation conditions and assumptions

Using the agents, and demand curve and hedging profile discussed above, we ran simulations for the four alternative trading arrangements. Three years of trading was simulated, 750 working days, with summary statistics for each of the 24 hourly settlement periods calculated from the final 250 working days of data. For the Pool day-ahead model this means that over 50 thousand separate daily bids decisions were simulated, while the bilateral short-term model simulates over 1.2 million hourly bids[6].

Though data on the quantity, and distribution, of forward contract cover in the current Pool is commercially sensitive, we know that, in general, all IPPs with CCGT plant, nuclear generators, and interconnector trade almost fully contracted and hence we have assumed a target utilisation rate of 100% for those companies. For Eastern, National Power, and PowerGen we assume an average target utilisation rate of 60% across their plant portfolios. In our simulation of the Pool day-ahead market, this accounts for 97.1% of total industry output. This value is consistent with levels of contracting reported anecdotally, and in Government inquiries (MMC, 1996a, MMC, 1996b).

5.2. Results

Simulated market clearing prices, for each of the four sets of trading arrangements, are summarised in Figure 2. These show that the current Pool day-ahead market, with Pay SMP settlement, and single daily bids, produces the lowest prices while the bilateral model with Pay Bid settlement, and hourly bids, produces the highest prices. As we have used identical demand patterns, agent costs, plant portfolio profiles, starting conditions, and random number sequences, we can ascribe this result solely to the change in trading arrangements between simulations.

Figure 3 shows the aggregate supply functions bid by agents under the four different sets of trading arrangements. Both of the Pay SMP settlement simulations show most baseload plant is bidding at close to zero, a strategy seen in the real Pool day-ahead market, which is truly emergent from the model because this behaviour is not explicitly specified in the agents' decision rules. In contrast, using exactly the same decision rules, agents quickly learn to bid a much flatter supply function, well above zero, when Pay-Bid settlement applies. This gives us confidence that the model is capable of successfully replicating both the actual, and potential, micro-level strategic behaviour in this market.

We know from observing real bidding and from analysis done by Helm & Powel (1992), Powel (1993), and Green (1996b), that the optimal bidding strategy for generators with hedged plant, is to bid at short-run avoidable cost. Therefore prices in the Pool day-ahead market do not reflect purely competitive bidding,

[6] Agents are modelled as data arrays in Excel 97 and manipulated with Visual Basic. This allows run speeds of approximately 2 minutes per year (Pool day-ahead), and 6 minutes per year (bilateral short-term), on a standard desktop PC equipped with a 400 MHz Pentium processor and 128 MB of RAM.

because forward contract cover limits generator's ability to exercise market power. In general, therefore, the higher the level of contracting, the lower the expected level of prices.

Figure 2. Simulated market clearing prices for alternative trading arrangements

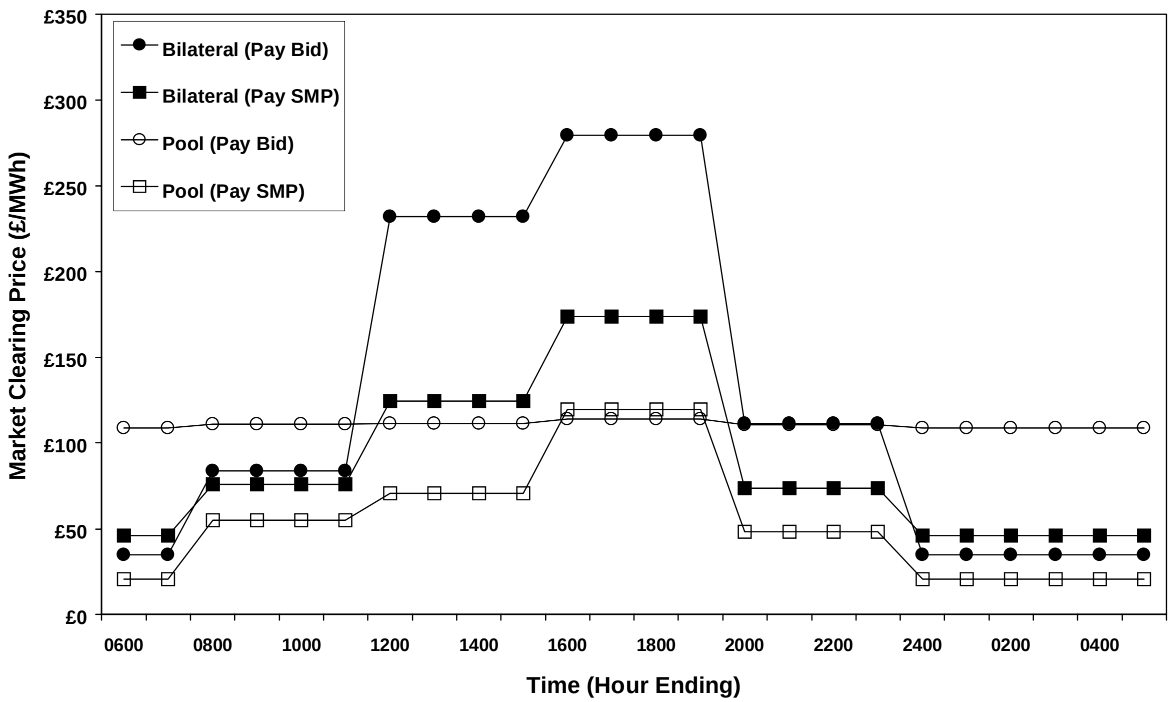
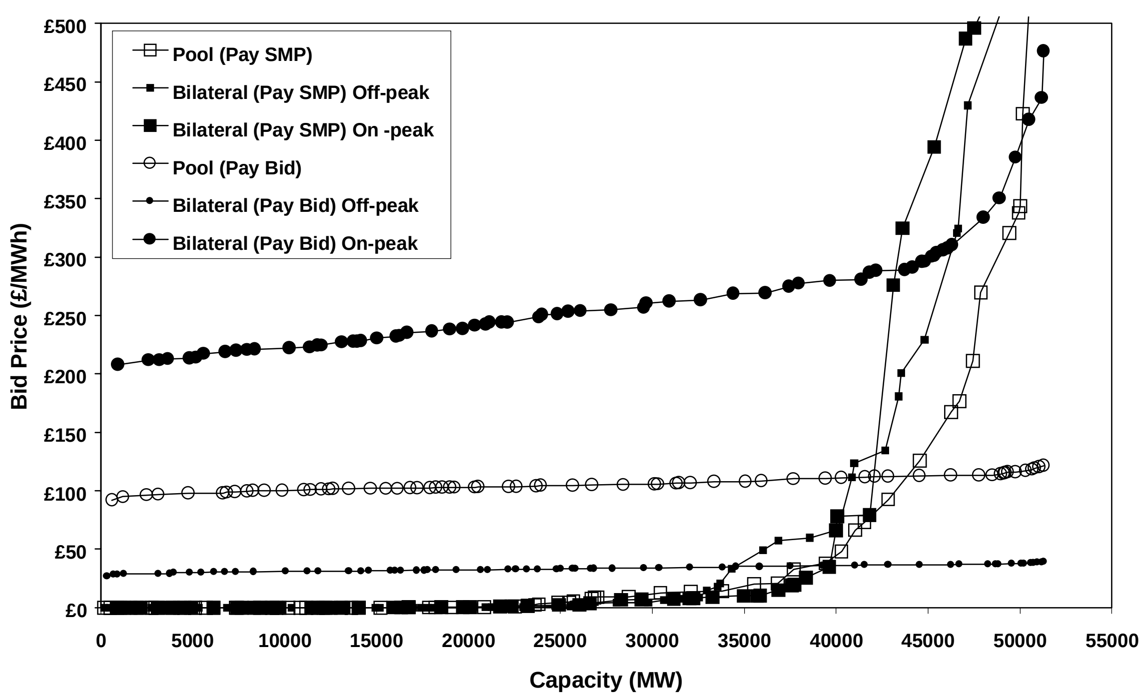
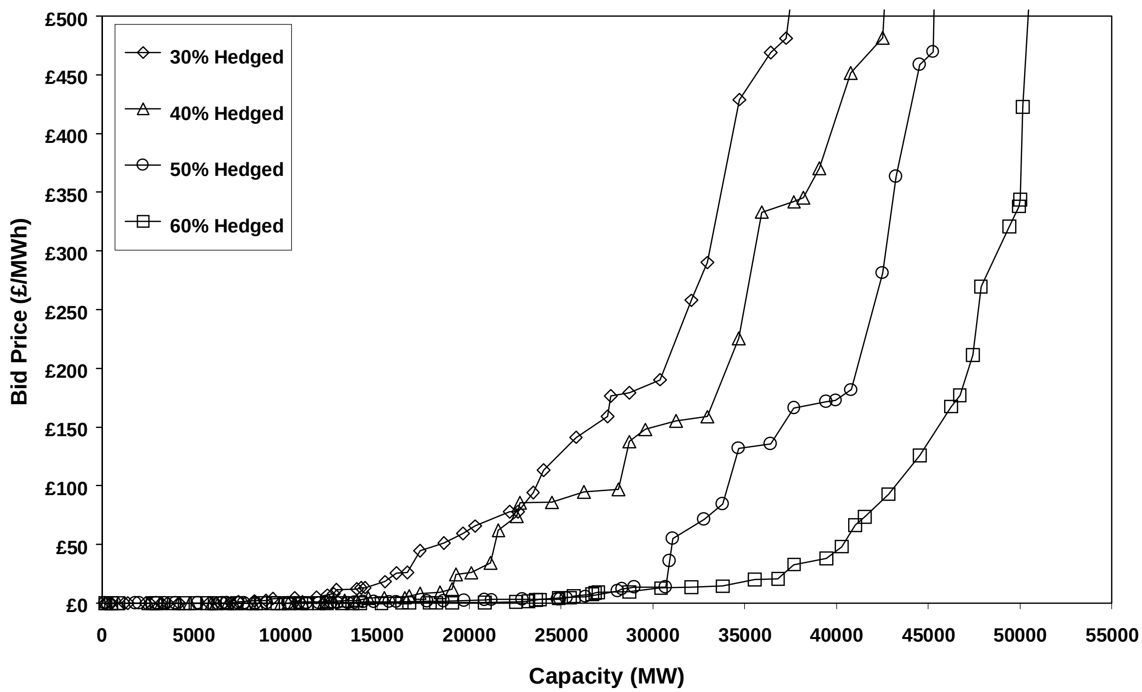


Figure 3. Simulated supply functions for alternative trading arrangements



We have been able to replicate these well-known findings, summarised in Figure 4, by changing the target rate of utilisation for Eastern, PowerGen, and National Power. For both, the Pool day-ahead simulation, and the bilateral short-term simulation, prices fall as the target rate of utilisation (i.e. generators' desire for market share) rises.

Figure 4. Impact of target utilisation rate on simulated market clearing prices for Pool Pay SMP



5.3 Discussion

The results, described above, seem to contradict OFFER's expectation that prices will fall as a result of the introduction of the bilateral model. Closer inspection of the bidding strategies of individual plants in our simulations reveals that this is due to two separate, but complementary, phenomena that result in:

i) Pay Bid settlement increasing the risk of over-bidding by baseload generators, especially IPPs with small plant portfolios, which reduces competitive pressure on generators with mid-merit plant; and

ii) hourly bidding allowing generators to effectively segment demand into on-peak and off-peak hours, thereby extracting a greater proportion of the consumer surplus than under daily bidding.

5.3.1. Analysis of Pay Bid versus Pay SMP effect on price

In the Pool day-ahead simulations, the Pay Bid price is generally higher than with Pay SMP. The same result occurs in the bilateral short-term simulations with Pay Bid producing on-peak and off-peak prices higher than with Pay SMP settlement.

In Table 3., the sales weighted average bid price for each generator has been calculated. This confirms that under Pay SMP settlement simulation the interconnectors, IPP CCGT, and nuclear baseload operators bid all their plant at prices close to zero. Conversely, under Pay Bid settlement simulation the sales weighted average bid price of baseload generators rises to a level similar to the mid-merit generators because they are being forced to bid closer to the market clearing price in order maximise their profits. This change in behaviour is exactly what OFFER wants to encourage, rather than allowing baseload plant to just bid zero and leave the market price setting to mid-merit plant.

However, Table 4. shows that Eastern, National Power, and PowerGen produce a greater percentage of total output under Pay Bid than under Pay SMP settlement. It seems that moving to Pay Bid settlement does not increase competition, as is hoped, rather it diminishes it, because the risk of baseload plant being underbid by mid-merit plant is increased. Baseload generators bid zero in the current Pool day-ahead market in order to eliminate this risk, and to guarantee that their plants keep running at all times. In short, forcing baseload generators to participate in price setting appears to reduce competitive pressure on mid-merit generators, rather than increase it, which allows prices to rise.

Table 3. Sales weighted average off-peak and on-peak bid prices under alternative trading arrangements

	Pool Pay SMP		Pool Pay Bid		Bilateral Pay SMP		Bilateral Pay Bid	
	Off-peak	*On-peak*	*Off-peak*	*On-peak*	*Off-peak*	*On-peak*	*Off-peak*	*On-peak*
Eastern	£ 21.13		£105.55		£ 2.93	£ 6.07	£ 28.74	£359.37
Interconnectors	£ 0.05		£ 97.12		£ 6.57	£ 5.73	£ 28.24	£231.48
National Power	£ 12.14		£103.11		£ 5.47	£164.39	£ 30.77	£257.42
Nuclear	£ 1.65		£102.78		£ 1.34	£ 4.03	£ 32.02	£222.89
PowerGen	£ 10.47		£104.24		£ 0.09	£ 74.26	£ 33.21	£263.52
IPP CCGT	£ 4.48		£ 99.51		£ 1.69	£ 4.68	£ 30.09	£228.81

Table 4. Generator average daily output under alternative trading arrangements

	Pool Pay SMP		Pool Pay Bid		Bilateral Pay SMP		Bilateral Pay Bid	
	MWh	% Total	MWh	% Total	MWh	% Total	MWh	% Total
Eastern	91,108	9.6%	93,702	10.0%	86,343	9.3%	83,195	9.1%
Interconnectors	68,218	7.2%	60,669	6.5%	67,918	7.3%	63,768	7.0%
National Power	208,684	22.0%	221,930	23.8%	202,875	21.8%	203,971	22.3%
Nuclear	234,522	24.7%	229,185	24.6%	234,434	25.2%	230,651	25.3%
PowerGen	194,534	20.5%	196,807	21.1%	189,326	20.3%	192,283	21.1%
IPP CCGT	150,648	15.9%	130,241	14.0%	150,502	16.2%	139,449	15.3%

The reduction in market share under Pay Bid settlement for baseload generators is compounded by the fact that, on average, they are achieving a sales price which is approximately 10-15% lower than mid-merit generators. This suggests that baseload generators would have to shade their bids in order to ensure their plants were able to run continuously in the bilateral model. Although simulated market prices are higher under Pay Bid, suggesting all generators would benefit the expense of consumers, mid-merit generators could gain disproportionately more because of their gain in market share and their higher average sales price.

Some older CCGT will soon be effectively operating on a merchant basis, or closer to the marginal cost of coal plant, which means that mid-merit plant operators would be competing in the same portion of the load curve. The mid-merit generators, using their large plant portfolios, could strategically increase the risk faced by these IPP operators by bidding in such a way as to force cycling of their plants perhaps several times per day. This will increase fuel use during start-up mode, and bring well known but unquantifiable risk of damage to turbine blades through increased thermal expansion and contraction. Eventually, this could significantly increase CCGT plant outages, further reducing competition to mid-merit operators in the short-term, and could even deter some new entry by IPPs in the long term even if the gas moratorium were removed. Baseload operators, particularly smaller IPP CCGT operators, would therefore face greater risk of losing revenue from overbidding, being inadvertently overhedged from overbidding, have increased fuel costs, and suffer more outages because of an increase in operational risk.

These findings are consistent with the earlier conclusion that OFFER drew after its previous inquiry into trading arrangements when it noted that:

“In sum, paying generators their bid prices would represent a major change which seems likely to have disadvantages in terms of increasing risks, particularly to smaller generators, without a strong likelihood that prices will be lower, In the longer term it could lead to higher prices” (Offer, 1994a).

5.3.2 Hourly versus daily bidding effect on price

Simulated prices for on-peak bilateral short-term market are higher than in the Pool day-ahead market for Pay SMP settlement. A similar pattern emerges for Pay Bid settlement which shows that, regardless of the settlement method used, a shift to hourly bidding in the bilateral short-term market produces a rise in price.

The reason for this apparent difference can be seen in Table 3. where sales weighted average bid prices are calculated for demand peak (hour ending 18.00) and demand trough (hour ending 06.00). The difference in bid prices between these two hours is obviously zero with single daily bids but in the bilateral model, especially with Pay Bid, differences of around 700% appear between on-peak and off-peak. Moreover, under SMP settlement it seems that one generator can more easily dominate the price setting process, with hourly bidding, than with daily bidding. Daily bidding forces generators to try and optimise their bids horizontally, across 24 hours, but with hourly bidding it seems they can more easily optimise, and perhaps even tacitly collude, in any given hour.

Economic theory tells us that firms should try and charge more to those customers who are willing to pay more for their goods, by segmenting the demand curve and differentiating their product offering, hence extracting the consumer surplus that would be lost if a single price were charged. Discriminating between customers on the basis of their willingness to pay is very easy in the electricity market because domestic customers are almost entirely unresponsive to price but demand proportionately more during on-peak hours, while industrial customers are sensitive to price and demand proportionately more at off-peak times. In this case, customers clearly signal their willingness to pay by the time at which they use the product. Allowing generators to bid significantly different prices, on the same plant, at different times allows them to exploit this information. It seems that the bilateral model could disproportionately increase generator market power, especially during on-peak hours when demand is highest, raising demand weighted average prices significantly. This could also significantly increases the risk of very large price spikes, if unexpected plant outages occur, and especially during very cold weather when plant margin is naturally low.

6. Conclusion

The bilateral trading proposal made by OFFER clearly has a number of attractive features, most notably the scrapping of capacity and availability payments, and the introduction of firm, simple, bids. However, these reforms could be just as easily implemented in the current Pool, effectively making SMP the market price for electricity. Combining these reforms with a more transparent bidding, and price setting mechanism, could also lead to more demand-side participation, and hence greater price elasticity. The results from our ABS model strongly suggest that the current Pool should produce lower prices than the bilateral model, therefore, we can conclude that modifying the current Pool would be more likely to deliver a price reduction than implementing OFFER’s bilateral model proposal. However, as generators have market power, they could easily compensate for any marginal increase in demand side response, or loss of capacity and availability payments, by raising SMP through modified bidding strategies. Regardless of whether the current Pool, a modified Pool, or the bilateral model is eventually implemented the fundamental issue of generator market power remains unresolved. This raises the question of whether a more thorough reform of the industry’s structure would be a far more effective, less expensive, and less risky, way of reducing market prices.

The review of trading arrangements also raises a number of questions about the way in which market reforms have been carried out in other countries. Argentina, Chile, and Colombia have been successfully using pool-based trading arrangements, for some time, while Alberta, New South Wales, Victoria, Spain and California have done so more recently. In contrast, Finland, New Zealand, Norway, and Sweden have adopted pure bilateral model arrangements, with great success, an which the Netherlands is set to copy. Meanwhile, various forms of bilateral model and pool-based trading coexist in different regions of the US. Inevitably, this raises the question as to which mechanism is best, particularly in those markets where reform has yet to get underway. Our results suggest that, although bilateral trading arrangements apparently do work well in some countries, there are factors specific to the England & Wales context which mean the current Pool, or a variant of it, may be a better solution. The interaction effects between industry structure, generation fuel mix, and alternative trading arrangements are clearly in need of further investigation.

With regard to making the wholesale electricity market work more like a commodity market, the history and everyday experience of spot and derivative commodity markets shows that where either supply or demand side is dominated by a few large players liquid markets do not develop. Put more simply, giving the market the trappings of a regulated commodity exchange, by creating a short-term, screen-based futures market, is very unlikely to reduce generator market power. This is especially true if they have the option to trade on a private, unregulated, illiquid, and opaque forward market where they face little threat from electricity, or financial market, regulators. Moreover, as even the most competitive and widely traded commodity markets show, wherever even temporary market power exists this can lead to massive price and capacity squeezes which deter speculative trading and hedging activity, causing liquidity to contract, and the essential process of price discovery to collapse.

In this paper we have deliberately focused our attention on the review of trading arrangements and have not attempted to address the question of the underlying industry structure. Recent moves by OFFER to force further plant divestment by National Power and PowerGen represent an important alternative route to reform of trading arrangements. Unfortunately, given the current OFFER timetable, both are likely to be implemented at the same time which means it will be difficult to identify what the relative impact the two initiatives, if any, will be. To this end, we believe that the ABS model we have presented is a powerful and flexible way of investigating a wide range of the potential industry restructuring scenarios. As far as reform of the Pool goes, one lesson that we should have learned from the experience of the last ten years is that a new electricity market should not be introduced simply as an act of faith. In this respect prior modelling is a useful way to develop intuition and to challenge untested ideas.

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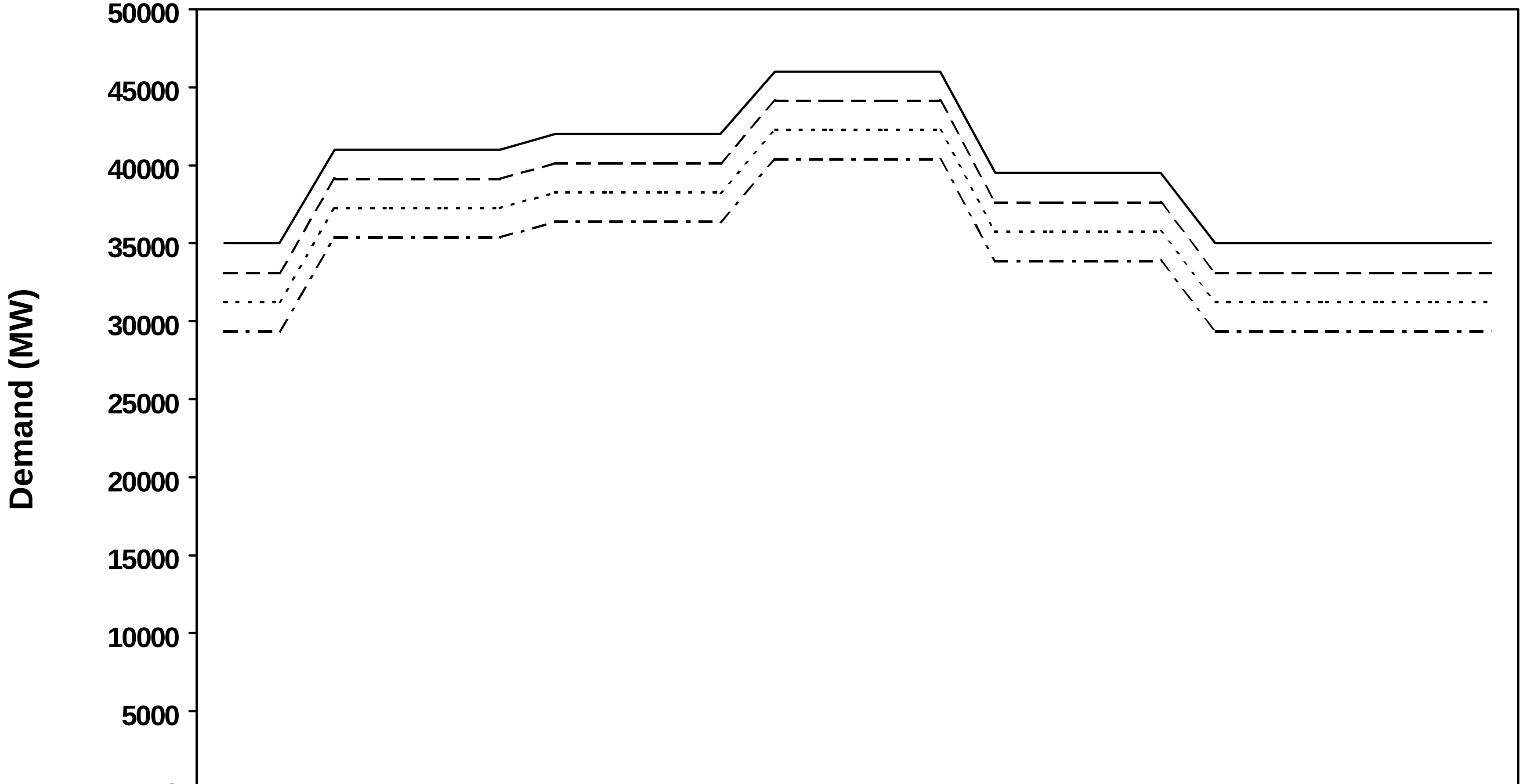
Appendix A. Agent specification

Centrally despatched plant data taken from NGC Seven Year Statement 1997/98 (Figures 3.4, 3.5 and 3.6) and includes all plant operating by 31 December, 1997 with estimates of real operational capacity and reliability during 1998. Marginal fuel costs are based on open market prices prevailing during 1998. Long term, fixed price, fuel contracts are ignored in the analysis.

Plant Number	Owner Firm	Plant Location	Plant Type	Operational Capacity (MW)	Unplanned Outage	Mean Available Capacity (MW)	Contracted Capacity (%)	Mean Contract Capacity (MW)	Marginal Cost (£/MWh)
1	Barking Power	Barking	CCGT	1000	11.90%	881.00	100.00%	881.00	£7.87
2	BNFL	Chapel Cross	Nuclear	196	9.40%	177.58	100.00%	177.58	£1.00
3	BNFL	Sellafield	CCGT	168	11.90%	148.01	100.00%	148.01	£7.95
4	Corby Power	Corby	CCGT	406	11.90%	357.69	100.00%	357.69	£7.95
5	Derwent Cogen	Derwent	CCGT	236	11.90%	207.92	100.00%	207.92	£7.87
6	Eastern	Kings' Lynne A	CCGT	380	11.90%	334.78	100.00%	334.78	£7.73
7	Eastern	Peterboro	CCGT	405	11.90%	356.81	100.00%	356.81	£8.19
8	Eastern	West Burton	L Coal	1972	12.50%	1725.50	60.00%	1035.30	£17.49
9	Eastern	Rugeley B	L Coal	996	12.50%	871.50	60.00%	522.90	£17.49
10	Eastern	Ironbridge	L Coal	970	12.50%	848.75	60.00%	509.25	£17.64
11	Eastern	Drakelow C	M Coal	976	24.50%	736.88	60.00%	442.13	£19.74
12	Eastern	H. Marnham	M Coal	945	24.50%	713.48	60.00%	428.09	£20.32
13	Eastern	Various	OCGT	90	12.00%	79.20	60.00%	47.52	£33.30
14	EDF	France Export	Nuclear	1988	5.00%	1888.60	100.00%	1888.60	£1.00
15	ENRON	Teeside	CCGT	1875	11.90%	1651.88	100.00%	1651.88	£8.03
16	First Hydro	Dinorwig	P. Store	Not included	Not included	Not included	Not included	Not included	Not included
17	First Hydro	Ffestiniog	P. Store	Not included	Not included	Not included	Not included	Not included	Not included
18	Humber Power	South Humber 1	CCGT	793	11.90%	698.63	100.00%	698.63	£7.73
19	Indian Q. Power	Indian Queens	OCGT	Not included	Not included	Not included	Not included	Not included	Not included
20	Lakeland Power	Roosecote	CCGT	229	11.90%	201.75	100.00%	201.75	£8.11
21	Magnox	Wyfla	Nuclear	1050	9.40%	951.30	100.00%	951.30	£1.00
22	Magnox	Hinkley A	Nuclear	475	9.40%	430.35	100.00%	430.35	£1.00
23	Magnox	Dungeness A	Nuclear	445	9.40%	403.17	100.00%	403.17	£1.00
24	Magnox	Oldbury	Nuclear	440	9.40%	398.64	100.00%	398.64	£1.00
25	Magnox	Sizewell A	Nuclear	430	9.40%	389.58	100.00%	389.58	£1.00
26	Magnox	Bradwell	Nuclear	240	9.40%	217.44	100.00%	217.44	£1.00
27	Magnox	Calder Hall	Nuclear	192	9.40%	173.95	100.00%	173.95	£1.00
28	Medway Power	Medway	CCGT	700	11.90%	616.70	100.00%	616.70	£7.80
29	Nat. Power	Didcot B 2	CCGT	690	11.90%	607.89	60.00%	364.73	£7.44
30	Nat. Power	Didcot B 1	CCGT	670	11.90%	590.27	60.00%	354.16	£7.58
31	Nat. Power	Little Barford	CCGT	680	11.90%	599.08	60.00%	359.45	£7.87
32	Nat. Power	Deeside	CCGT	500	11.90%	440.50	60.00%	264.30	£7.87
33	Nat. Power	Killingholme NP1	CCGT	650	11.90%	572.65	60.00%	343.59	£8.19
34	Nat. Power	Drax B	L Coal	1935	12.50%	1693.13	60.00%	1015.88	£10.80
35	Nat. Power	Drax A	L Coal	1935	12.50%	1693.13	60.00%	1015.88	£11.43
36	Nat. Power	Aberthaw B	L Coal	1455	12.50%	1273.13	60.00%	763.88	£11.66
37	Nat. Power	Eggborough	L Coal	2005	12.50%	1754.38	60.00%	1052.63	£11.83
38	Nat. Power	Tilbury B	M Coal	680	24.50%	513.40	60.00%	308.04	£11.91
39	Nat. Power	Didcot A	L Coal	1960	12.50%	1715.00	60.00%	1029.00	£12.07
40	Nat. Power	Blythe B	M Coal	626	24.50%	472.63	60.00%	283.58	£12.72
41	Nat. Power	Blythe A	S Coal	456	5.00%	433.20	60.00%	259.92	£13.52
42	Nat. Power	Littlebrook D	Oil	685	23.75%	522.31	60.00%	313.39	£14.13
43	Nat. Power	Fawley	Oil	484	23.75%	369.05	60.00%	221.43	£14.29
44	Nat. Power	Willington B	M Coal	188	24.50%	141.94	60.00%	85.16	£14.48
45	Nat. Power	Various	OCGT	270	12.00%	237.60	60.00%	142.56	£27.30
46	Nat. Power	Various	OCGT	269	12.00%	236.72	60.00%	142.03	£27.30
47	Nuclear Elec	Heysham 2	Nuclear	1320	9.40%	1195.92	100.00%	1195.92	£1.00
48	Nuclear Elec	Hinkley B	Nuclear	1300	9.40%	1177.80	100.00%	1177.80	£1.00
49	Nuclear Elec	Hartlepool	Nuclear	1237	9.40%	1120.72	100.00%	1120.72	£1.00
50	Nuclear Elec	Sizewell B	Nuclear	1220	9.40%	1105.32	100.00%	1105.32	£1.00
51	Nuclear Elec	Heysham 1	Nuclear	1148	9.40%	1040.09	100.00%	1040.09	£1.00
52	Nuclear Elec	Dungeness B	Nuclear	1104	9.40%	1000.22	100.00%	1000.22	£1.00
53	PowerGen	Connah's Quay	CCGT	1500	11.90%	1321.50	60.00%	792.90	£7.44
54	PowerGen	Rye House	CCGT	740	11.90%	651.94	60.00%	391.16	£7.58
55	PowerGen	Killingholme PG1	CCGT	940	11.90%	828.14	60.00%	496.88	£8.03
56	PowerGen	Cottam	L Coal	2008	12.50%	1757.00	60.00%	1054.20	£11.55
57	PowerGen	KingsNorth	L Coal	1940	12.50%	1697.50	60.00%	1018.50	£11.57
58	PowerGen	Ratcliffe	L Coal	2000	12.50%	1750.00	60.00%	1050.00	£11.62
59	PowerGen	Ferrybridge C	L Coal	1470	12.50%	1286.25	60.00%	771.75	£11.77
60	PowerGen	Fiddler Ferry	L Coal	1950	12.50%	1706.25	60.00%	1023.75	£11.78
61	PowerGen	Grain	Oil	2025	23.75%	1544.06	60.00%	926.44	£15.46
62	PowerGen	Various	OCGT	163	12.00%	143.44	60.00%	86.06	£27.30
63	PowerGen	Various	OCGT	163	12.00%	143.44	60.00%	86.06	£27.30
64	Regional Gen	Brigg	CCGT	272	11.90%	239.63	100.00%	239.63	£7.95
65	Rocksavage Pow.	Rocksavage	CCGT	760	11.90%	669.56	100.00%	669.56	£7.65
66	Scot Power	Scot. Export 3	L. Coal	655	5.00%	622.25	100.00%	622.25	£11.68
67	Scot. Hydro	Scot. Export 1	Hydro	349	5.00%	331.55	100.00%	331.55	£0.10
68	Scot. Hydro	Keadby 1	CCGT	710	11.90%	625.51	100.00%	625.51	£7.87
	Totals			58709		51285		38617	

Plant Type	Total Operational Capacity (MW)	Mean Unplanned Outage (%)	Total Available Capacity (MW)	Notional Contracted Capacity (%)	Notional Contracted Capacity (MW)
Hydro	349	5.00%	332	100.00%	332
Nuclear	12785	8.72%	11671	100.00%	11671
CCGT	14304	11.90%	12602	82.19%	10357
L. Coal	23251	12.29%	20394	61.22%	12485
M. Coal	3415	24.50%	2578	60.00%	1547
S. Coal	456	5.00%	433	60.00%	260
Oil	3194	23.75%	2435	60.00%	1461
P. Store	0	0.00%	0	0.00%	0
OCGT	955	12.00%	840	60.00%	504
TOTAL	58709	12.65%	51285	75.30%	38617

Appendix B. Standardised load profile



	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500
£75/MWh	35000	35000	41000	41000	41000	41000	42000	42000	42000	42000	46000	46000	46000	46000	39500	39500	39500	39500	35000	35000	35000	35000	35000	35000
£150/MWh	33125	33125	39125	39125	39125	39125	40125	40125	40125	40125	44125	44125	44125	44125	37625	37625	37625	37625	33125	33125	33125	33125	33125	33125
£225/MWh	31250	31250	37250	37250	37250	37250	38250	38250	38250	38250	42250	42250	42250	42250	35750	35750	35750	35750	31250	31250	31250	31250	31250	31250
£300/MWh	29375	29375	35375	35375	35375	35375	36375	36375	36375	36375	40375	40375	40375	40375	33875	33875	33875	33875	29375	29375	29375	29375	29375	29375

Time (Hour Ending)