Market Power in Electricity Markets:

Do Electricity Markets Require Special Regulatory Rules?

A Report Concerning the Competition Commission Electricity Generators Inquiry

by

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1 Introduction and Summary

The purpose of this report is to address the issue of whether electricity markets differ significantly from other markets with respect to the analysis and diagnosis of market power. Ofgem (2000c)(2000d) have argued that the characteristics of electricity markets make them particularly vulnerable to the exercise of market power by both large and small firms. This is the primary justification for their proposal to amend the licences of eight of the generating companies operating in the England and Wales electricity wholesale market to include a market abuse prohibition. Ofgem have argued that standard competition policy rules - such as those embodied in the Competition Act 1998 and Article 82 (86) of the Treaty of Rome - do not suffice to control the potential for market abuse because of the special and unique features of electricity wholesale markets.

In this report we will demonstrate that Ofgem's arguments are without foundation. We do so largely by referring to the voluminous theoretical and empirical literature on the exercise of market power in restructured electricity markets around the world. In our view there is no basis for the claim that wholesale electricity markets differ significantly from other markets with respect to the analysis, diagnosis, or control of abuses of market power. Hence there is no need for special regulatory rules designed to deal with the putative exercise of market power by 'small' firms. While we agree with Ofgem that there are particular market power issues which can and do arise in electricity networks, and which may have no immediate counterparts in non-network industries, these can and should be dealt with by normal competition policy rules, once the nature of these problems has been correctly diagnosed.

In the remainder of this section we first summarise the position of Ofgem and the arguments it has proffered to justify the introduction of a market abuse condition in the licences of eight electricity generation companies. We then sketch the results of our survey of the economic literature on this subject, and our conclusions with respect to the particular market power issues raised by Ofgem.

1.1 Ofgem's Position

In their submissions to the Competition Commission, and elsewhere (Ofgem 2000a, 2000b, 2000c, 2000d), Ofgem argue that the particular nature of electricity wholesale markets and electricity networks make them especially, or uniquely, prone to the abuse of market power, in particular by 'small' firms. Ofgem cite:

- the need for instantaneous (real time) matching of supply and demand to maintain system security and quality of supply
- the non storability of electricity
- the limited ability of the demand-side to respond to price movements in the short term

According to Ofgem, *"…these physical and economic characteristics make it possible for participants with very small market shares (measured either on an output or capacity basis) who are offering to sell electricity close to 'real time' to set or substantially influence prices, for example, by changing their bidding strategies or by withholding generation capacity."* (Ofgem, 2000c, paras 1.4-1.5)

Ofgem therefore believe that under the current trading arrangements, *"companies which account for at least 5% of output or of system marginal price setting may possess substantial market power and have the ability to abuse substantial market power."* (Ofgem, 2000d, para 3.1). Under the NETA arrangements Ofgem evidently believes that the incentives of some companies to manipulate the market may actually increase. (Ofgem, 2000d, para 3.10)

As examples of market abuse by 'small' firms Ofgem cite:

a) manipulation of price bidding strategies to raise market prices independently of changes in underlying supply and demand conditions, including manipulation of forward contractual positions to increase both contract prices and prices in the physical market;

b) exploiting market power resulting from local transmission constraints;

c) capacity withholding to increase market prices, in particular by manipulating the capacity payment mechanism under the existing trading arrangements; and

d) manipulation of complex market rules to increase prices and earn excessive profits.

Ofgem argue that neither the Competition Act 1998 nor Article 82 (86) of the EC Treaty of Rome provide it with sufficient powers to regulate market abuse because these apply specifically to abuses by dominant firms, i.e. typically firms with in excess of 30 - 40% of the relevant market, whereas*, "…in the circumstances of the wholesale electricity market, generators can and have caused abnormal price movements, even when they account for a small share of output or capacity."* (Ofgem 2000a, para 3.15). They have therefore proposed a licence condition prohibiting market abuse which is specific to eight firms operating in the England and Wales electricity market, none of which, according to Ofgem, would satisfy standard criteria for dominance.

1.2 The Arguments of this Report

We argue in this report that Ofgem's proposed licence condition prohibiting abuse of market power by 'small' firms cannot be justified by a rigorous economic analysis of competition in wholesale electricity markets. In particular we demonstrate that the claim that the unique or special features of electricity markets make them particularly vulnerable to abuses of market power by 'small' firms[1] is without economic foundation. Where specific market power issues do

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[1] That is, firms which are not dominant in the relevant market.

arise in electricity markets, these can be dealt with by standard competition policy rules, at least when an economically coherent approach to market definition is taken. There is therefore no basis for the claim that electricity markets require special regulatory rules to control abuses of market power by 'small' firms.

Theoretical and Empirical Literature

To demonstrate this we first survey the academic literature concerned with the analysis of market power in decentralised electricity markets. This literature has grown rapidly in recent years, and there are now entire journals devoted to the subject. However none of the standard analyses of competition in restructured or decentralised electricity markets leads to the conclusion that electricity markets, or networks, are particularly prone to the exercise of market power by 'small' firms. Indeed all concentrate attention exclusively on the exercise of market power by firms with large market shares (i.e. dominant firms). For example, the theoretical analyses of von der Fehr and Harbord (1993) (1998) and Green and Newbery (1992) (also Green, 1996) have the property that an increase in the number of firms leads to a reduction in market prices and firms' profits. That is, the ability of firms to exercise market power decreases as market concentration decreases. This property is shared with all standard models of oligopolistic competition. The conclusion that market power and market concentration are positively correlated is robust across auction types and market designs.

When transmission constraints are introduced into the analysis, this conclusion can change in the sense that firms which are 'small' in the aggregate market may possess 'local market power', i.e. have an incentive to bid above marginal cost whenever part of the their generation assets are constrained-on. The ability to exercise market power in electricity networks may therefore depend upon strategic location, and not simply aggregate market shares. Hence an understanding of the power flows over the transmission system can be an important prerequisite for conducting a comprehensive market power analysis in the electricity industry.[2]

The analysis of dynamic aspects of competition in electricity markets points in the same direction as the static analyses. Although it has been argued that daily repeated wholesale electricity auctions may be particularly prone to collusion (Rothkopf, 1999; Armstrong, Cowan and Vickers, 1994; Klemperer, 2000), the economic analysis of this issue does not differ from that of other markets. The literature on forward contracts, entry and investment reinforces these results (Newbery, 1998; von der Fehr and Harbord, 1992; von der Fehr and Harbord, 1997). These analyses confirm the general argument of Wilson (1999) that forward markets tend to have a procompetitive effect in electricity spot markets, and mitigate market power. Newbery (1998) argues that long-term contract markets make the England and Wales pool a 'contestable' market by facilitating the entry of IPPs (independent power producers). von der Fehr and Harbord

[2] Ofgem (2000c)(2000d), of course, suggest that this implies that market power problems in electricity networks cannot be dealt with using normal competition rules. We will argue below that although the diagnosis is at least partially correct, the cure is misconceived.

(1997) show that oligopolists in electricity markets may underinvest or overinvest in generation capacity, however as the number of firms increases, investment approaches its 'first-best', or perfectly competitive, level.

Empirical studies and market simulations – notably by Green and Newbery (1992), von der Fehr and Harbord (1993)(1995), Wolak and Patrick (1997), Wolfram (1998) (1999), and researchers at the University of California Energy Institute – strongly confirm these theoretical findings. All of these studies find that it is large firms which exercise or abuse market power in restructured electricity markets, although smaller firms will typically benefit when large firms set high prices. The recent large-scale simulation study of Gruenspecht and Terry (2000) undertaken for the US Department of Energy, for instance, nicely summarises the conclusions of previous researchers. They identify two key factors which facilitate the exercise of market power in restructured electricity wholesale markets, namely:

- high levels of ownership concentration; and
- limited transmission capacity from adjacent areas, i.e. high concentration in regions separated by transmission constraints.

Wolfram's (1998) empirical analyses of bidding behaviour in the England and Wales market comes to even more specific conclusions, *vis.* that the larger generators in the UK market bid higher prices than their smaller competitors for units with comparable costs. These results are consistent with Newbery's (1992) prediction that larger suppliers submit prices reflecting larger mark-ups over marginal cost than do smaller firms. International experience to date in restructured and competitive electricity markets bears out these conclusions.

We conclude from this that there is no rigorous basis in economic analysis for the claim that wholesale electricity markets differ significantly from other markets with respect to the diagnosis or control of abuses of market power. Restructured electricity markets are now amongst the most intensively studied markets in the world. None of the evidence presented in the large theoretical and empirical literature which now exists on the subject implies a need for special regulatory rules to deal with the exercise of market power by 'small' firms.

Specific Issues

These broad conclusions carry over immediately to the analysis of the specific examples of market abuse by 'small' firms cited by Ofgem in their submissions to the Commission:

1. Strategic bidding in spot and forward markets to raise market prices independently of changes in underlying supply and demand conditions

This issue is generic to all markets in which large or dominant firms have an ability to exercise market power. Most wholesale electricity markets around the world are subject to the abuse of market power by large firms, although no other regulator to our knowledge has yet seen fit to request an extension of its powers of market surveillance to encompass firms with less than 15% or 20% of the relevant market. Evidence for strategic bidding to raise prices (SMP) in the England and Wales pool relates almost exclusively to the historical price bidding strategies of the dominant generators, National Power and PowerGen. The same is true in every other wholesale electricity market. Ofgem's examples of strategic bidding by 'small' firms to increase market prices are all examples of the manipulation of poorly designed and complex market rules, e.g.

- price spikes attributed to TXU and Brigg in 1998/99 were examples of the manipulation genset inflexibility markers, elbow points, and a complex price determination algorithm embodied in GOAL
- Ofgem's recently announced investigation into capacity withholding by Edison under the new market abuse condition, where the concern is the effect on capacity payments

These forms of (alleged) market abuse by 'small' firms will be eradicated when the new trading arrangements are introduced.

The exercise of market power in forward or contracting markets does not differ in kind from its exercise in the electricity spot market or pool. Large firms with market power will exercise it in whatever market yields the greatest returns. This could conceivably consist of taking forward contractual positions to increase both contract prices and prices in the real time physical market, as suggested by Ofgem. However what evidence exists on this subject suggests that forward markets are more likely to have a significant procompetitive effect rather than the reverse.

2. Transmission constraints and local market power

Transmission constraints, as previously noted, can lead to firms which are relatively 'small' in the aggregate market having substantial degrees of market power in particular regions for particular periods of time. This issue has arisen in a number of restructured electricity markets, including Norway, California, and England and Wales. The literature on this subject is now extensive.[3] However, once it is recognised that transmission constraints - like congestion or interruptions in any transportation network - can lead to geographically separated markets in which only a small number of firms compete, standard approaches to defining the relevant market immediately lead to the conclusion that such firms are 'dominant' in the relevant market. Hence standard approaches to market definition and the definition of dominance are entirely adequate to the task, and these should be employed.

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[3] See the references cited in Section 3.2 below.

Further, a coherent regulatory approach would be to deal specifically with those companies that are in a position of 'local market power' for significant periods of time, and impose regulatory measures designed to deal with the problem, as has been done in California for instance.

3. Manipulation of the capacity payment mechanism

This has indeed been a source of market manipulation - and higher prices - in the England and Wales pool, where it arises uniquely. Wolak and Patrick (1997), for instance, have identified capacity payments as a 'high powered mechanism' for increasing electricity prices and firms' profits. Ofgem itself has recognised the flaws in this mechanism, and its irrational approach to measuring 'the probability of lost load. [Ofgem 2000c]. This issue has been the focus of attention in a number of regulatory investigations since privatisation and will disappear entirely in November 2000 with the introduction for the new electricity trading arrangements. Even if this were not the case it would nevertheless obviously be preferable to abolish, or reform, the capacity payment mechanism, rather than introduce a catch-all measure designed to strengthen regulatory powers well beyond those found necessary in other industries. Again, it is important to note that practically all of the instances of abuse or manipulation of this mechanism reported by Ofgem have been by National Power or PowerGen, and during the first five years of the market, when these companies were dominant firms.

4. Manipulation of complex market rules

Ofgem's view that electricity markets are by their very nature unusually complex is not accepted by economists or auction theorists who have become increasingly involved in designing markets for electricity in recent years. Nor is it true that complexity by itself necessarily leads to increased potential for the abuse of market power. However electricity markets do have the unique feature that the market rules are often designed by engineers rather than by skilled economists, and the resulting complexity can make the detection and the control of abuses of market power more difficult. In extreme cases, badly designed market rules can also create opportunities for market manipulation and abuse that should not exist. The England and Wales pool has been particularly, and perhaps uniquely, prone to this problem. Ofgem's example of 'price spikes' attributed to the bidding behaviour of TXU in 1998/9 for instance, is clearly an example of a manipulation made possible by a complex price determination algorithm which even the regulator has frequently had difficulty in understanding.[4] Manipulations of the new electricity trading arrangements which were uncovered in the recent market experiments are also of this type.[5]

Standard economic principles of market design are however sufficient to deal with these issues, and should be used. These principles allow us not only to predict

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4 Offer (1992).

5 I.e. a consequence of a poorly designed price determination mechanism based on manipulable averages. See Harbord and McCoy (2000) and London Economics (1999b) for further explanation.

how particular market rules will effect firms' market strategies, but also provide guidance on the details of good market designs. Where market rules allow for profitable manipulation they should be changed. Recent experience in auction design in electricity and in other areas, such as recent US and UK auctions for the radiospectrum, has demonstrated the effectiveness of economic analysis in this area.

Defining and Diagnosing Market Power

The theoretical analysis of competition in wholesale electricity auctions leads to other important conclusions which raise doubts about Ofgem's approach to identifying which firms have the potential to exercise market power. The most important of these is that identifying firms which are at the 'margin', i.e. set market prices, for significant periods of time, would appear to have little or nothing to do with the identification of which firms possess market power. This is because:

- firms which bid in all of their capacity at marginal cost may well be the firms that are most successfully, i.e. in a Nash equilibrium, exploiting their market power; and
- if all firms bid in all of their capacity at marginal cost, at various times of the day different firms would be observed setting system marginal price, but this would tell us nothing about which firms could potentially exercise market power.

Hence both of Ofgem's criteria for identifying firms with market power, i.e. *"companies which account for at least 5% of output or of system marginal price setting"* are flawed and lack foundation in any rigorous economic analysis.

We consider three more traditional approaches to the definition and diagnosis of market power in electricity wholesale markets:

(i) price-cost comparisons, as proposed in von der Fehr and Harbord (1993), Wolak and Patrick (1997), and Wolfram (1998) (1999a);

(ii) residual demand analysis; and

(iii) concentration measures or market share analysis

Each of these approaches can be based on a properly undertaken and rigorous analysis of competition in electricity wholesale markets, and each has value when used appropriately.

1.3 Conclusions

That the England and Wales electricity pool has been subject to the abuse of market power by the dominant thermal generators is probably beyond dispute. Both the economic theory of competition in electricity wholesale markets, and the empirical evidence, provide overwhelming confirmation of this fact. The market has also been subject to manipulations of its complex price-determination rules. Since the England and Wales market was amongst the first to be restructured, it is perhaps not surprising that it has been particularly subject to problems of market power and market manipulation. Electricity market reforms in other countries have benefited from this experience. The UK regulatory authorities however, appear to have been slower to learn from their own experience in this area, or to grasp the nature of the underlying problems and their solutions.

Most economists recognise the unique and interesting features of decentralised electricity wholesale markets, which have important implications both for good market design, and for appropriate forms of regulatory oversight. None of these features, however, means that electricity markets differ *qualitatively* from other markets with respect to the analysis, diagnosis, or control of abuses of market power. On the contrary, the large theoretical and empirical literature which now exists on these subjects is testimony to the efficacy of traditional economic analysis in this area.

Ofgem's proposed licence condition prohibiting abuse of market power by 'small' firms therefore finds no support in the economic analysis of electricity markets. We demonstrate in this report that the claim that the unique or special features of electricity markets make them particularly vulnerable to abuses of market power by 'small' firms (i.e. firms that are not dominant in the relevant market), is without economic foundation. Where specific market power issues do arise in electricity markets, these can be dealt with by standard competition policy rules, at least when a sensible and economically coherent approach to market definition is taken. There is no basis for the claim that electricity markets require special regulatory rules to control abuses of market power by 'small' firms.

1.4 Structure of the Report

Section 2 of this report summarises and explains the economic analysis of competition in wholesale electricity spot markets in both static and dynamic contexts, including the analysis of the longer-run issues of contracts, entry and investment. Section 3 surveys the now extensive empirical research and market simulations which have been carried out to study the potential for the exercise of market power in restructured electricity markets. Section 4 then analyses the key examples of market power and its abuse raised by Ofgem in their submissions. Section 5 discusses the regulatory approach which we believe should be taken toward the analysis, diagnosis and measurement of market power in electricity wholesale markets. Section 6 concludes.

2 Analysis of Competition and Market Power in Electricity Markets

That wholesale electricity markets possess unique features which are not shared by most other markets is beyond dispute. These features derive from some well-known characteristics of electricity as a commodity, and have important implications for the organisation and design of electricity markets. Robert Wilson, one of the architects of the California Power Exchange, explains this as follows:

> *"From the viewpoint of standard economic theory, wholesale markets for electricity are inherently incomplete…. Some incompleteness is inevitable*

> *because electricity is a flow (rather than a stock) that cannot be metered perfectly, and storing potential energy is expensive. Further, flows on transmission lines are constrained continuously by operational limits and environmental factors, and ramping rates of generators are limited. The flow aspect means that a property right cannot be assigned by title. No one owns electricity per se; rather, qualified market participants obtain privileges to inject or withdraw power from the transmission grid at specific locations. Thus, all rights are reciprocal and derived from contracts.*
>
> *The chief economic consequence … is that within a short time frame a fully efficient, decentralized market solution is not feasible presently. This means that real-time operations are conducted by a system operator using procedures influenced more by engineering than economic considerations, and invoking directives when markets fail. There can be only one spot market, the one conducted by the system operator as an integral part of its technical management of the transmission system, using offers in the spot market and pre-arranged reserves to maintain stability of the system, or directives if these are insufficient."* [6]

An electricity spot market, or 'pool', is therefore unlike virtually any other market in that it must match demand and supply continuously over the day in order to maintain network 'electrical equilibrium'. This means that no matter how 'centralised' or 'decentralised' the market design, near to 'real time', each generating unit must follow the operating instructions of a central despatcher or system operator (SO).

In different countries, different approaches to dealing with this co-ordination problem have been adopted. In England and Wales, Australia, Spain (and elsewhere), a 'mandatory' day-ahead auction has been created, and all physical trades in electricity take place via the pool. In other countries (or regions) a sequence of forward (year-ahead, day-ahead) and 'real time' markets have been organised in which all markets are 'voluntary' (California, Norway, and most recently, the NETA proposal). The distinction between these two types of market design can, however, be exaggerated. In systems with 'mandatory' pools, a great deal of trade takes place in forward markets for financial contracts. And as Wilson (1999) points out, *"all forward transactions are inherently financial",* since physical commitments made in forward markets can be reversed by purchases or sales in real time spot markets. Even in so-called 'decentralised' systems, with a sequence of voluntary forward and spot markets, near to 'real time' the system operator must intervene to ensure that the pre-arranged trades are physically feasible, or else recontracted.

This inherent incompleteness of electricity wholesale markets, implying a lack of a fully decentralised solution, means that even under the 'New Electricity Trading Arrangements' envisaged for England and Wales, which have been specifically designed to permit a greater degree of 'contractual freedom' in electricity trading, the system operator must ultimately have the authority to 'undo' such trades or

6 Wilson (1999).

contracts (by accepting 'incs' and 'decs' in the 'balancing' market) to ensure that system stability and security requirements are met.[7]

Given the central role played by the 'real time' spot market in wholesale electricity markets, it is not surprising that economic analysis to date has been largely focused on the operation of these markets. This is especially natural given that:

- the first deregulated systems (with the exception of Norway), were all organised as 'mandatory' day-ahead spot markets; and
- prices in the real-time electricity spot market will be the primary determinant of forward traders' price expectations, which are a crucial determinant of the forward trades agreed to in any prior contract markets or power exchanges

Fully informed traders with rational expectations will of course not make forward trades which relinquish profitable trading opportunities in the spot market.[8] Even without rational expectations however, expected spot prices will remain the primary determinant of forward trades. The analysis of competition in the electricity spot market is therefore fundamental to any understanding of competition and the exercise of market power in electricity wholesale markets generally, including forward markets.

All electricity spot markets, or 'pools', which have been created to date have been organised as first-price, multi-unit auctions. This applies to both 'mandatory' and 'voluntary' real-time pools, as well as to the electricity forward markets in Norway and California.[9] Competition in these markets occurs by generators submitting 'price-quantity' bids which specify the minimum prices at which they are willing to supply energy, and the amount of output or capacity available at each price. On the basis of these price-quantity offers, a least-cost plan of generating units (i.e. an industry supply curve) is drawn up. This rank order (in

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7 See Hogan (2000) for a particularly clear statement of this. The crucial role played by the system operator in 'real time' markets requires a remarkable degree of centralised control. The SO must be advised of all physical, forward contractual positions in order to balance the system, and is responsible for coordinating *all* physical trade in electricity, even in those systems in which the real time 'balancing' market is meant to be for marginal, extra-contractual trades only. Hence the 'centralised/decentralised' distinction which is often used in this context, is at least partly illusory. Issues of overall market design, or 'architecture', are nevertheless extremely important, even if the pros and cons of the different market organisations are to date only partially understood by economists and regulators alike. Wilson (1999) - a proponent of a more 'decentralised' approach to electricity market design - provides a brilliant and concise discussion of these issues.

8 von der Fehr and Harbord (1992) contains an early analysis of forward trading under rational expectations in a deregulated electricity market. See also Newbery (1998).

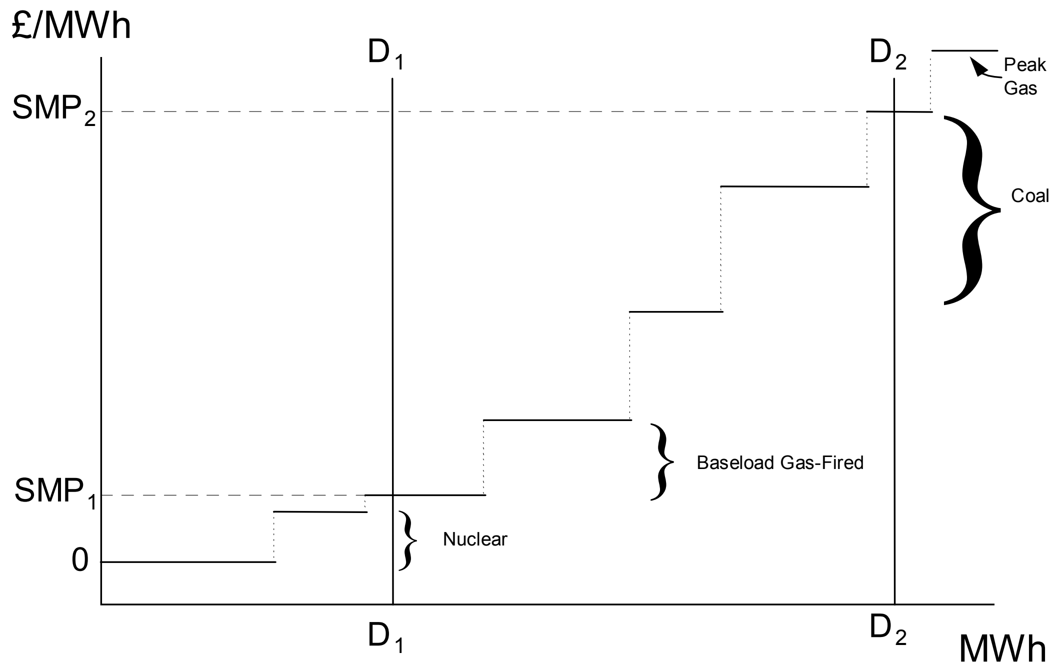
9 See von der Fehr and Harbord (1993) and Klemperer (2000), Section 6.1, for more on this. The only exception is the proposed new balancing market for England and Wales in the NETA programme, which is organised as a 'discriminatory' or 'pay-your-bid' auction, and which will be discussed separately below.

industry parlance, a 'merit order') of generating units, together with a forecast of demand, determines which units will be despatched in any particular period.

Prices are determined for each period by the bid price of the marginal unit, hence reflecting the changing balance between demand and supply over the day. As demand varies, different types of plant, with different operating and capital costs, are despatched at the margin to meet it. The short-run marginal cost of electricity production - or *system marginal price (SMP)* - which determines prices, varies correspondingly. Ex ante, or expected, pool prices may be published in advance to allow larger electricity consumers to adjust their demands to this price information. Actual prices are typically determined by the interaction of the generators' bids with demand, random capacity outages and transmission constraints. Figure 2.1 below depicts the price determination process in electricity pools, based upon a stylised 'merit order' or generation supply curve.

Electricity spot markets are thus well-defined market institutions with a well-specified price-setting mechanism by which generators prices and quantity bids are translated into market prices and quantities. In studying strategic behaviour in pools, it is both possible and necessary to employ models of the actual market institution in question, and in particular the auction price-setting mechanism, since this will typically have profound effects upon the analysis of strategic behaviour and the exercise of market power. This price-setting mechanism is not the standard one employed in economic textbooks to describe pricing behaviour in decentralised markets (i.e. it does not correspond to textbook versions of either Bertrand or Cournot competition).

Figure 2.1 Stylised Merit Order



2.1 Static Oligopoly Analyses

Nevertheless, a natural first step in analysing competition in electricity spot markets would be to apply one of the standard models from the theory of imperfect competition. This approach has been adopted with some success - in particular to demonstrate that competition in the England and Wales pool is unlikely to result in perfectly competitive outcomes (Vickers and Yarrow, 1991; Wolfram, 1999).[10]

In this section we discuss three approaches to understanding the nature of price competition in electricity spot markets which have been suggested in the literature. The first of these is an application of standard oligopoly theory: the *'capacity-constrained Bertrand competition'* model, which although of questionable value in the analysis of strategic behaviour in first-price auctions, forms a good starting point for the discussion of discriminatory, or 'pay your bid', electricity auctions. We then describe two models that more directly take into account the specific features of electricity pools. The first is Green and Newbery's adaptation of the *'supply function'* model due to Klemperer and Meyer (1989). The second is the *'multi –unit auction model'* of the current authors. Finally, we discuss two models which directly account for the effects of transmission constraints on competition in electricity wholesale markets (Cardell, Hitt and Hogan, 1997 and Nasser, 1997, 1998).

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10 It has also been used as the basis for empirical studies and market simulations, which are discussed in Section 3 below.

In Sections 2.2 and 2.3 we turn to a discussion of dynamic models of competition, including the analysis of collusion, forward contracts, entry and investment.

2.1.1 Capacity-constrained Bertrand competition

In the standard model of Bertrand competition, identical sellers with constant unit costs and no capacity constraints compete to supply the market on the basis of price offers to consumers. This form of competition inexorably leads identical sellers to price at marginal cost; a price offer above cost will be undercut by another seller since it results in positive profits, and a lower price offer would result in losses (see, for instance, Tirole, 1988, Ch 5).

However no existing electricity spot market is a standard Bertrand price game of this kind. At the very least, as pointed out by Armstrong, Cowan and Vickers (1994, Ch 9), it is more like Bertrand competition with capacity constraints. Under this form of competition prices will not typically be equal to marginal costs, and indeed may considerably exceed them. Although the analysis of equilibrium pricing behaviour in capacity-constrained oligopoly is complex (see Tirole, 1988, 209-216; also Kreps and Scheinkman, 1983), Armstrong *et al* provided a simple argument to demonstrate that marginal cost pricing was unlikely to be an optimal bidding strategy for the dominant generators in the England and Wales pool in 1990.[11] Except in extremely low demand periods, neither of the two thermal generators alone was typically able to satisfy all of demand. And even when PowerGen, Nuclear Electric and the interconnectors were operating at full capacity, National Power remained the market's residual supplier, and hence retained substantial residual market power.[12] For a large part of the year bidding at cost would therefore not be optimal, and indeed would be a 'dominated strategy', i.e. not optimal no matter what the other generators were bidding. Hence pool prices would be unlikely to reflect marginal supply costs for much of the year. This would not have been the case, however, if National Power's capacity had been split between three companies and PowerGen's between two, creating five strategic players rather than two. Then, in many if not most periods, no single generator's capacity would have been required to satisfy market demand, and pricing strategies would have likely been much more competitive (Armstrong, Cowan and Vickers, 1994, p. 303).[13]

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11 Their discussion was based on the market's industrial structure in 1990, and hence focused on the strategies of the 'duopolist' thermal generators at that time, National Power and PowerGen.

12 See Section 5 for a discussion of the relationship between residual demand and market power in electricity markets.

13 Armstrong *et al* recognise that their exposition of bidding strategies in the pool is simplistic, but argue that it is nevertheless sufficient to show that given the duopoly industrial structure created at the time of privatisation, "*..the electricity pool could not be expected to operate for much of the time as a normal competitive market. This is a damaging criticism, not least because of the importance of marginal cost bidding for the efficiency of the system as a whole."*

While highly suggestive, the treatment of Armstrong *et al* did not formally analyse the equilibrium bidding behaviour of the generators in the pool. In particular, the logic of their 'dominated strategy' argument assumes a pricing mechanism in which each generator is paid its own bid price for each unit of capacity despatched, rather than the price bid of the marginal operating unit, as in the England and Wales pool. This can lead to fundamental differences in the analysis of equilibrium bidding strategies. To understand better the likely bidding behaviour in the pool therefore, it is necessary to model more formally the actual bidding game being played by generators in the market.

Nevertheless, their account of Bertrand competition with capacity constraints does describe reasonably accurately competition in a discriminatory, or pay-your-bid, electricity auction, and hence is of some relevance for understanding bidding strategies in the balancing mechanism to be introduced under NETA. It also exposes a crucial aspect of the analysis of market power under any market design or auction format (discussed in greater detail in Section 5 below). In order to possess market power a firm (or generator) must face some 'residual demand' in at least some periods, i.e. be the residual supplier in the market. Clearly a larger firm is more likely to be in this position than a smaller one, hence firm size and market concentration have much to tell us about the potential for exercising market power in electricity markets, as they do in any other market.

2.1.2 The supply function model

Green and Newbery (1992) analysed competition in the British electricity spot market using the 'supply function equilibria' approach of Klemperer and Meyer (1989), and calibrated the model to the circumstances of the industry at the time of privatisation. The approach has since been used to model contracts and capacity divestments in the England and Wales pool (see Newbery, 1998; Green, 1996).

Klemperer and Meyer (1989) modelled an oligopoly facing uncertain demand, and argued that in such an environment firms would prefer to set supply functions, rather than compete in prices (Bertrand competition) or quantities (Cournot competition). They observed that under demand uncertainty - given any hypothesised behaviour by other firms (i.e. price or quantity setting) - the residual demand facing each firm is uncertain, and hence each firm has a set of profit maximising points, one corresponding to each realisation of its residual demand. If firms must decide on their strategies in advance of the realisation of demand, then they are better off specifying an entire supply curve, rather than a single price or quantity.[14]

Green and Newbery's (1992) model of the British electricity spot market is a translation of the Klemperer and Meyer (1989) model. They observed that

[14] A major difficulty with the theory of course, is to explain how firms are able to commit themselves to a particular supply function. This difficulty does not arise in the application to the electricity spot market, which forces generating companies to commit themselves in advance to a supply schedule.

demand uncertainty as represented by Klemperer and Meyer is formally identical to demand variation over time, and hence that the analysis may be used to model competition in the England and Wales electricity pool. In doing so they hoped to characterise the bidding behaviour of the generators in the pool.

Using the supply function approach, Green and Newbery (1992) assumed that strategic generators submit continuously differentiable supply functions to the pool, rather than discrete step functions (i.e. a bid for each generating unit), and that the market equilibrium was the static one-shot supply function equilibrium. They also assumed that the two thermal generators-National Power and PowerGen - were the only strategic players in the market, and that Nuclear Electric, Electricité de France and the independent power producers simply bid in their capacity at zero. As in the Klemperer and Meyer model, the equilibrium solution to this duopoly game lies between the price-setting Bertrand equilibrium and the quantity-setting Cournot equilibrium.

Their approach then yields a continuum of possible equilibria, bounded above by the Cournot outcome and below by the perfectly competitive equilibrium. Given this result, the range of possible solutions to the model is probably too large to yield useful predictions (see Newbery, 1999 for a recent discussion). Green and Newbery (1992) however went on to argue that when capacity constraints are introduced, the range of possible equilibria is reduced, because no firm will wish to supply along a schedule which reaches its capacity before the maximum demand is reached.[15]

Green and Newbery did not extend their model of the electricity market to encompass more than two strategic firms. However Green (1996) solved a tractable class of examples for the supply function model to analyse whether divestment of capacity by National Power and PowerGen would be more efficacious than entry in improving market performance. Depending upon how the bidding behaviour of the new firms created by divestment was modelled, Green found a significant reduction both in average pool prices and overall (deadweight) welfare losses resulted from even a relatively small divestiture of around 15% of each of the duopoly generators' capacity. He also showed that if National Power and PowerGen were split into five, equally-sized firms, deadweight losses from the exercise of market power were practically eliminated. Green (1996) argued that divestiture was a better option for increasing both competition and economic welfare than was new entry by CCGTs. Although entry drove down average pool prices, the benefits were eventually offset by the costs of constructing new power stations in a market in which there was no shortage of thermal generation capacity.

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15 See also Newbery (1992). A number of criticisms of the Green and Newbery (1992) model have since been made. See Wolak and Patrick (1997) and von der Fehr and Harbord (1998) for a discussion, and Newbery (1999), p. 282, for a response.

2.1.3 The multi-unit auction model

Unlike Green and Newbery (1992), von der Fehr and Harbord (1993) modelled competition in the England and Wales wholesale electricity market as a first-price, sealed-bid, multi-unit auction.[16] As Paul Klemperer (2000) has recently noted, this approach was once seen as unorthodox, but no longer:

> *"It was not initially well-understood that deregulated electricity markets, such as in the U.K., are best described and analysed as auctions. … Now, however, it is uncontroversial that these markets are best understood through auction theory."*

Wolfram (1999b), who has made auction theory the basis of her own recent empirical work on electricity markets (see Section 3.1 below), concurs:

> *"The characterization of electricity markets as auctions merits comment. Auctions are simply organized markets where goods are awarded to bidders based on specific rules that determine who wins the auction and the price the winning bidder pays. Auctions can be used either to sell products (e.g. wine, artwork, or the right to drill for oil in the Gulf of Mexico) or to award contracts to potential suppliers (e.g. for road construction projects). Auctions of the second type are called procurement auctions, since a product is being procured rather than sold. Electricity markets are structured as procurement auctions*."

That decentralised electricity spot markets are auctions, and hence best understood through auction theory, is now so well understood that much of the recent debate in Britain concerning the reform of the electricity trading arrangements has focused on the merits and demerits of different auction formats.[17] Fabra, Harbord and von der Fehr (2000) have recently extended the model of von der Fehr and Harbord (1993) to permit a comparison of market performance under different auction rules in light of this debate. We briefly summarise the results of both these analyses in what follows.

von der Fehr and Harbord (1993)

The purpose of the von der Fehr and Harbord analysis was to address the issues of market power and market performance in a formal model specifically designed to capture the essential elements of new electricity pricing system in England and Wales. Not unlike the informal analysis of Armstrong, Cowan and Vickers (1994), their analysis emphasised the sensitivity of optimal bidding strategies in the pool to the relationship between residual demand and the capacities of the large,

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[16] In particular they analysed bidding strategies in the electricity pool for firms with discrete generating units, rather than continuous supply functions. They argued that this made a fundamental difference to the equilibrium analysis of bidding strategies. For other analyses of competition in electricity markets based on the multi-unit auction model see García-Díaz and Marín (2000) and Stachetti (1999).

[17] Harbord and McCoy (2000), Klemperer (2000) and Wolfram (1999b) contain discussions of this debate.

strategic generators. It demonstrated that there was likely to be both inefficient despatch and above-cost pricing given the concentrated market structure in England and Wales in 1992.

The analysis in von der Fehr and Harbord (1993) focused on duopoly, although many of the results were generalised to the oligopoly case. In the interests of brevity and simplicity we limit ourselves here largely to describing the key results for the case of two strategic generators, and briefly discuss how and where results extend to the case of oligopoly.[18]

A simple version of the generator bidding game analysed in von der Fehr and Harbord (1993) is the following. The model considers two generators each having constant marginal costs, c_1 and c_2, up to their capacities. It is assumed that $c_1 \leq c_2$, i.e. firm 1 is at least as efficient as firm 2. The total capacity of each generator is fixed and given by k_n, n = 1,2, with the capacity of each generator divided into m_n generating units. Thus the model allows for asymmetries in both marginal costs and capacity levels for the two firms. Although the marginal cost for each generating unit owned by a single firm is assumed constant, the generators are able to submit different bids for each of their generating units.[19]

The generators simultaneously submit bids to the pool specifying the prices, $p_{ni} \leq \bar{p}$, $i = 1,2,...,m_n$, at which they are willing to supply electricity from each of their generating units. The firms' offer prices are constrained to be below some threshold level $\bar{p}$, since otherwise, for levels of demand in which all units may be called into operation, the generators' expected payoffs could be made infinitely large, given that demand is perfectly price inelastic. In the England and Wakes pool, system marginal price cannot exceed the 'value of lost load' (approx. £2 per kWh in 1992), so this is a realistic assumption. Perhaps more importantly, the threat of regulatory intervention is likely to impose a much lower ceiling on price bids (see Wolak and Patrick, 1997, for a discussion).

On the basis of these bids or offer prices, the system operator constructs a least cost market supply curve.[20] The level of demand d in any period is then determined as a random variable which is independent of prices.[21] The system operator then equates demand and supply and 'despatched' units, i.e. units called upon to supply electricity, are paid the market clearing price, which is equal to the price bid of the marginal operating unit (i.e. the last unit called into operation).

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18 The presentation here is a simplified version of the discussion in von der Fehr and Harbord (1998). For technical details and proofs see von der Fehr and Harbord (1992a).

19 This point is important, but frequently goes unnoticed – see Newbery (1999), Ch. 5.

20 If two or more generating units of any generator are offered at the same price, they are assumed equally likely to be called into operation.

21 The assumption of inelastic demand is realistic (in the short run), but could nevertheless easily be dispensed with (see von der Fehr and Harbord, 1997). Se also García-Díaz and Marín (2000) for an extension of von der Fehr and Harbord (1993) in which demand is taken to be downward sloping.

This model may be interpreted as a first-price, sealed-bid, multiple-unit auction in which all units are sold simultaneously. This interpretation is particularly convenient for analysing alternative pricing rules (see Fabra, Harbord, and von der Fehr, 2000).

Analysis and Results

The types of equilibria which can occur in this model of competition in wholesale electricity auctions depend crucially on the relationship between demand and the capacities of the two (or more) strategic generators. Three cases can be distinguished:

- 'low demand periods' in which any single generator can supply the whole of demand;
- 'high demand periods' in which no generator has sufficient capacity to supply the entire market (as discussed by Armstrong, Cowan and Vickers, 1994 above); and
- 'variable demand periods' in which there is positive probability for both the event that a single generator can supply the whole of demand, and the event that all generators will have units called into operation, irrespective of their price bids.

We briefly discuss each of these cases in turn.

Low Demand Periods

This case corresponds to the standard model of Bertrand oligopoly in the sense that there is a unique equilibrium in which the duopoly generators both offer to supply at a price equal to the marginal cost of the least efficient generator, as summarised in Result 1.

Result 1. If $d < \min\{k_1,k_2\}$ with probability one, there exist pure-strategy equilibria in all of which the market clearing price equals the marginal cost of the least efficient generator, c_2, and only generator 1 produces.

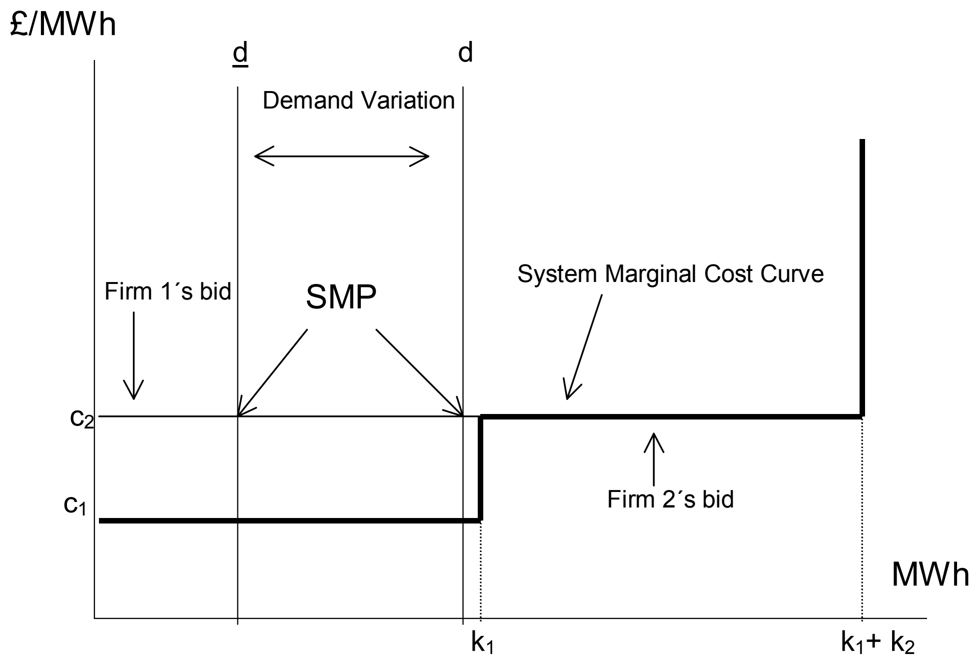
In this case demand can always be met by a single firm, implying that there will be fierce competition to become the single operating generator. In particular, a generator will always undercut its rival so long as its bids are above its own marginal costs. Thus any equilibrium must have the most efficient generator submitting offer prices for its capacity at or below the marginal cost of the less efficient generator. Since generator 1's profits are increasing in its own offer price, these bids must be equal to c_2. Hence in 'low demand periods' the system marginal price is bounded above by the marginal costs of the least efficient generator.

A similar result can be shown to hold in the oligopoly model. If, with probability 1, demand is less than the total capacity of the n most efficient generators, then in equilibrium system marginal price cannot exceed the marginal cost of the n+1st most efficient generator.

Figure 2.2 represents equilibrium bidding behaviour in a low demand period for the case of a duopoly with symmetric capacities and asymmetric costs, i.e. $k_1 = k_2$

and $c_1 < c_2$. As depicted, demand never exceeds the capacity of a single firm. In equilibrium, the more efficient firm 1 bids in all of its capacity at a price of c_2 , and serves all demand at that price.

Figure 2.2 Competitive Bidding in a Low Demand Period



High Demand Periods

High demand periods are periods in which with probability one both duopoly generators will have at least some units called into operation. In this case both generators always face some residual market demand, and hence have market power. Since the generator submitting the highest price bid will now be operating with certainty, and in equilibrium generators never submit equal bids,[22] its profit is increasing in its bid price. This means that the extreme opposite of the result of the previous section now holds. Whereas in low-demand periods the system marginal price equals the marginal cost of the least efficient generator, in high-demand periods SMP always equals the highest admissible price.

In high demand periods therefore, when neither generator has sufficient capacity to supply the entire market (but both generators together have excess capacity), the market price will be high with one generator bidding the maximum admissible price, while the other generator bids low and sells more output. Which generator makes which bid cannot be determined a priori. However in equilibrium the

[22] This follows from Proposition 1 in von der Fehr and Harbord (1993).

generators should behave in this fashion.[23] The characterisation of the pure-strategy equilibria is summarised in the following result:

Result 2. If $d > \max\{k_1\ k_2\}$ with probability one, all pure-strategy equilibria are given by offer-price pairs (p_1,p_2) satisfying either $p_1 = \bar{p}$ and $p_2 \leq b_2$ or $p_2 = \bar{p}$ and $p_1 \leq b_1$, for some $b_i < \bar{p}$, $i = 1,2$.

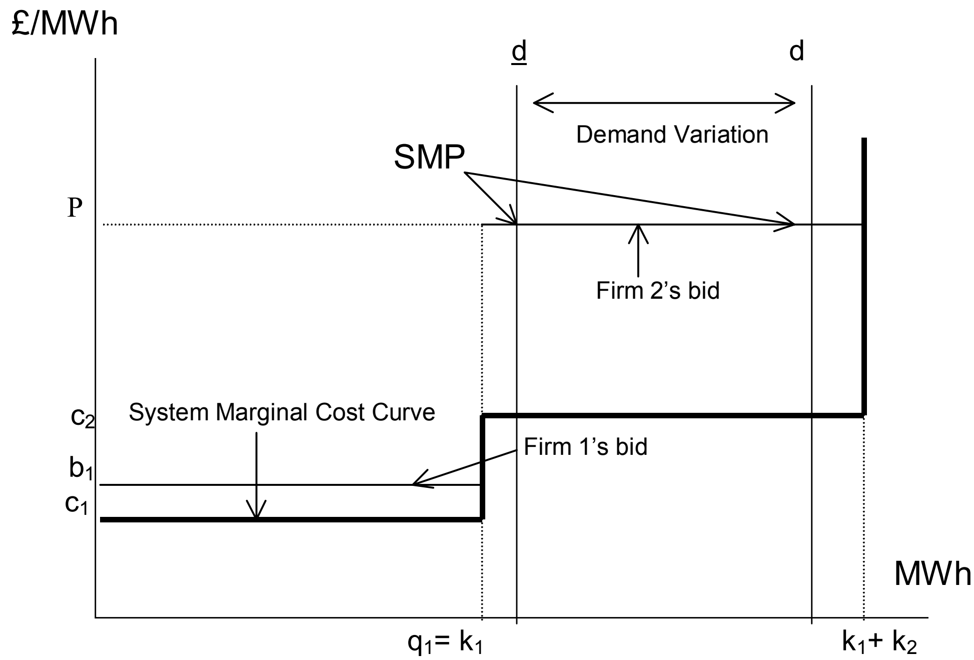
In all of the equilibria characterised by Result 2, the system marginal price equals the highest admissible price. Note that some of these equilibria will involve inefficient despatch of generating units. The high-cost generator may be the generator with the lowest bid and thus will be despatched with its total capacity, while the low cost generator is only despatched with part of its capacity. In such equilibria, generation costs are not minimised.

Figure 2.3 represents typical equilibrium bidding behaviour in a high demand period for a duopoly with symmetric capacities and asymmetric costs, i.e. $k_1= k_2$ and $c_1< c_2$. Demand is always greater than the capacity of either firm. The low bidding firm, firm 1 in this example, bids just above its own marginal cost, and is despatched with its full capacity.[24] Given firm 1's bid, firm 2 maximises its profits by bidding the highest admissible price and serving the residual demand (i.e. total demand net of firm 1's capacity).

Figure 2.3 Duopoly Bids in a High Demand Period

[23] Since in this game there are two asymmetric pure-strategy Nash equilibrium outcomes, in the absence of further information the equilibrium solution reached cannot be predicted from first principles. One solution is to consider the symmetric mixed strategy equilibrium. Another would be to predict that the generators will alternate between pure strategy equilibria. Other factors - such as the relative sizes of the generators - may single out certain equilibria as 'focal' (see Lucas and Taylor , 1993, for more on this).

[24] Hence bidding at marginal cost *does not imply an absence of market power*. On the contrary, this strategy earns the greatest duopoly rents. To see this, observe that if one of the two generators was able to make an advance commitment to a particular bidding strategy - that is, *if we endowed this generator with an even greater degree of market power* - its optimal strategy would be to bid at marginal cost, since the other generator would then be forced to bid high to maintain the pool price.



It is again easy to show that in the case of oligopoly we get a corresponding result. Whenever demand is such that the highest-bidding generator determines the system marginal price with probability one, any vector of offer prices such that this generator submits the maximum admissible price, while all other firms bid sufficiently below this, will be an equilibrium.

Variable Demand Periods

In the final case it is now assumed that demand may be either high or low with some (given) probability. To motivate this assumption, recall that in the England and Wales pool generators submit daily price bids, and their bids may therefore be constant for time periods in which demand is expected to be high (e.g. morning and afternoon) and periods in which it will be low (e.g. night time).[25] This variation in demand can be modelled as if generators faced a single period in which demand can be either low or high with some probability.[26] Equilibrium bids in this case are not the simple 'high-low' bids of the high-demand period case, nor the fiercely competitive bids of the low-demand period. In fact, pure strategy equilibria do not exist in this case, and hence the equilibrium is 'mixed strategies'. In a mixed strategy equilibrium each generator randomises its price bids over an interval bounded below by the least efficient generator's marginal costs, and

25 In the Scandinavian pool, the Spanish pool, and the Californian Power Exchange, different price bids may be submitted for each of the 24 hourly periods that the market is open. The variable demand case is consequently of less relevance in these markets. The same will apply to the balancing mechanism under NETA.

26 This is essentially the same observation as made in Green and Newbery (1992).

above by the highest admissible price. Expected pool prices will still typically exceed the marginal costs of generation, however what the pool price will be is the result of a random process, and cannot be predicted with certainty.

Result 3. If $\bar{d}-\underline{d} > \max\{k_1,k_2\}$, where $[\underline{d}, \bar{d}]$ is the support of the demand distribution, then there does not exist an equilibrium in pure strategies.

Since the range of possible demand distributions exceeds the capacity of the largest generator, it follows that for any strategy combination there is a positive probability that units of either generator will be the marginal operating unit.[27] Characterisation of mixed-strategy equilibria in the general model is cumbersome, and so in von der Fehr and Harbord (1993) an explicit solution was calculated only for a simple example in which the explicit form of the two players' strategies could be derived. An important property of the mixed strategy equilibrium in the general model however, is that the higher-cost generator's strategy profile 'first-order stochastically dominates' the strategy profile of the low-cost generator. Thus, in expected terms, the higher-cost generator will submit higher bids than the lower-cost generator.[28] However, it can be shown that, although the typical outcome is that the high-cost generator prices above the low-cost generator, there is a potentially significant probability that the high-cost generator submits the lowest price offer. Therefore, as in the high-demand case discussed above, the market is not ex-post efficient (i.e. there will be inefficient despatch of generating units with positive probability).

Oligopoly Analysis

In von der Fehr and Harbord (1993) the model described above was used to consider the question of how an increase in the number of independent generators will effect (average) pool prices, by extending the analysis to the case of oligopoly. Since the question of interest is how the number of suppliers in the market would affect average prices, they considered the situation in which the duopoly generators were split up into smaller, competing units, i.e. a given total capacity divided between a larger number of firms.

When, for a given level of demand and total capacity, more players are introduced into the market, there is a pro-competitive effect, i.e. prices will tend to be lower in the less concentrated industry. The intuition for this, for the case of variable demand periods, may be explained as follows: The probability of any generator setting system marginal price decreases as the number of generators increases. Hence the incentive to bid high in order to raise market price also decreases. The overall effect is to reduce the probability of any generator submitting a high bid, and hence of a high system marginal price.

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[27] This result follows directly from Proposition 1 in von der Fehr and Harbord (1993).

[28] This is true for equally sized generators. Using a similar set-up to von der Fehr and Harbord (1993), Wolfram (1997) has shown that a larger generator, with more inframarginal capacity, will tend to submit higher bids, and that the incentive to submit a higher bid is increasing in the amount of inframarginal capacity the firm owns. This is equivalent to saying that the optimal distribution for the generator with more inframarginal capacity 'first order stochastically dominates' the optimal distribution of its rival.

This intuition also suggests that in the more general model with multi-unit generators, prices will tend to be higher than in the model in which these same units act independently. As indicated above, raising the bid of one unit will have an external effect on other units in that it increases the expected system marginal price. A generator which controls many units will internalise part of this externality and will thus have an additional incentive to increase its offer prices. In particular, this 'co-ordination incentive' is stronger the more units an owner controls. It therefore seems reasonable to conclude that for a given number of generating units in the industry, the system marginal price will be a decreasing function of the number of owners, or generators controlling the units, i.e. the industry concentration ratio.

Fabra, Harbord and von der Fehr (2000)

Fabra, Harbord and von der Fehr (2000) extend the analysis of von der Fehr and Harbord (1993) to address some of the issues that have been raised by the recent redesign of the electricity trading arrangements in the UK. Amongst the proposed reforms is a new auction format. The regulatory authorities appear to believe that first-price, uniform auctions - such as that currently used in the pool, and in every other wholesale electricity market - are more subject to strategic manipulation by large generators than are discriminatory, or 'pay-your-bid' auctions, and hence result in higher average electricity prices.[29]

It is well-known by economists and auction theorists that this is not in general the case. Both uniform-price and discriminatory auctions are commonly used in financial and other markets, and there is now a voluminous economic literature devoted to their study.[30] In multi-unit settings the comparison between these two auction forms is complex, however, neither theory nor empirical evidence tell us that discriminatory auctions perform better than uniform price auctions in markets such as those for electricity.[31] The purpose of Fabra, Harbord and von der Fehr (2000) is therefore to evaluate these claims and counterclaims in a series of models which represent some of the key features of decentralised electricity markets, albeit within a simplified framework. These simplifications allow for direct comparisons in many cases.[32]

Whilst the debate in the UK has been focused on the advantages or disadvantages of uniform versus discriminatory auctions, amongst economists Vickrey auctions are often favoured. Vickrey auctions make sincere bidding a dominant strategy for traders and hence result in least cost production, or

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29 Ofgem "The new electricity trading arrangements", Volume 1, July 1999.

30 See Binmore and Swierzbinski (1997); also Ausubel and Cramton (1998).

31 Wolfram (1999), for instance, argues that the comparison is ambiguous, although she appears to favour uniform auctions. Bower and Bunn (1999) claim evidence that uniform auctions perform better in a detailed simulation model of electricity market competition.

32 Federico and Rahman (2000) compare uniform and discriminatory 'electricity' auctions for the cases of perfect competition and monopoly, with ambiguous results. In Fabra, Harbord and von der Fehr (2000) we analyse the cases of duopoly and oligopoly.

despatch efficiency. This comes at a cost since traders with market power need to be paid the 'opportunity costs' of their bids, and these payments can be large.[33] Vickrey auctions in markets such as those for electricity have to date received relatively little detailed analysis. von der Fehr and Harbord (1993)(1998) studied Vickrey auctions with reserve prices in electricity markets for some extremely simple cases, which the current analysis extends.

In a comparison of the one-shot Nash equilibria in the three types of auctions under different specifications of the 'electricity trading' game, Fabra, Harbord, and von der Fehr (2000) show the following:

- the Vickrey auction guarantees productive efficiency but leads in at least some cases to higher payments to firms (i.e. higher average prices) than the other two auction formats;
- equilibrium prices in the discriminatory auction are in some cases lower than in the uniform auction, but at the expense of greater productive inefficiency. In some circumstances, however, the ranking between the uniform and discriminatory auctions is reversed: indeed, it is possible for the uniform auction to strictly outperform the discriminatory auction, resulting in both lower prices and greater productive efficiency

Fabra, Harbord, and von der Fehr (2000) extend the comparative auction analysis in a number of directions. The important point for present purposes however, is that all three auction formats share the property that an increase in the number of firms selling in the market results in a decrease in market prices and an increase in overall economic welfare. In certain cases the 'procompetitive effect' from a decrease in market concentration is more pronounced in the uniform than in the discriminatory auction.

Discussion

The analysis of duopoly and oligopoly in von der Fehr and Harbord (1993) and Fabra, Harbord, and von der Fehr (2000) - like that of Green and Newbery (1992) and Green (1996) - demonstrates that the traditional relationship between market structure and market performance can be expected to hold in wholesale electricity auctions. All models exhibit a strong procompetitive effect when duopoly generators are broken up in to smaller competing units. An important caveat to all of these analyses however is that transmission constraints are ignored in the models. This subject has since been studied by Cardell, Hitt, and Hogan (1997) and by Nasser (1997)(1998), whose results we now briefly discuss.

2.1.4 Static oligopoly analysis with transmission constraints

Recent work by Cardell, Hitt, and Hogan (1997) and Nasser (1997)(1998) demonstrates that predicted behaviour by oligopolistic players may be different from behaviour implied by simpler models of competition in the electricity industry,

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33 Wilson (1999); Ausubel and Cramton (1999).

once the physical constraints imposed by the electric transmission grid are made part of the models of competition.

Cardell, Hitt, and Hogan (1997) model behaviour by oligopolists as a Cournot game embedded in a transmission network accurately reflecting physical power flows and producing nodal spot prices. They computationally derive equilibria under a variety of assumptions about market concentration and the allocation of transmission rights. They find that modelling the transmission system accurately leads to some surprising results concerning the exercise of horizontal market power, at least in a Cournot model. In particular, they find that a dominant firm may have an incentive to increase rather than decrease output, and lower prices at some locations as a means of exploiting the transmission constraints of the network and thereby foreclosing competition.[34] Their results provide some important, if well-understood, lessons for a market power analysis. In particular, the ability to exercise market power depends on strategic location, and not simply aggregate market share. Hence an understanding of the power flows over the transmission system may be an important prerequisite for conducting a meaningful market power analysis in the electricity industry.[35]

Nasser (1997) however argues that Cournot competition is not a realistic assumption for most electricity markets. He shows that in a model of price competition under perfect cost information in a transmission-constrained network, some players possess ‘local market power’, i.e. have an incentive to bid above marginal cost whenever some part of the their generating units are ‘constrained-on’. Nasser (1997) modelled competition as a simple auction in which each player's generation has constant marginal cost, and where each player has enough capacity to meet the entire perfectly inelastic demand.[36] In a simple three node example, he shows that certain players possess ‘local market power’ and, unless a maximum bid is specified, are able to extract potentially infinite rents. The ability of some sellers to profit from local market power depends crucially on the presence of limited transmission capacity. Transmission line limits create the need to despatch plants ‘out-of-merit’, i.e. some plants are needed even though their costs exceed the costs of other plants ‘constrained-off’ by a binding transmission limit.

These models thus arrive at slightly different, although still broadly similar, conclusions about the relationship between prices and seller concentration.

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34 This is because in the authors’ Cournot model with transmission constraints, a large generator may have an incentive to increase its production in one area to ‘block’ competing generation. As Nasser argues however (see immediately below), these ‘foreclosure’ results do not survive more realistic modelling of price competition in an electricity auction.

35 Ofgem (2000c)(2000d), of course, suggest that this implies that market power problems in electricity networks cannot be dealt with using normal competition rules. We disagree – see Section 4.2 below.

36 These assumptions correspond to a ‘low demand period’ in the von der Fehr and Harbord (1993) model. Nasser’s analysis extends this model to a more realistic representation of a transmission network.

Nasser's more realistic model suggests that prices are high at nodes where sellers have local market power. Cardell, Hitt, and Hogan (1997) actually find that a player with market power chooses output in a way that leads to a market price below the competitive level at some locations. It is, however true that, as a result of such behaviour, market prices are high at least at one location at which such a player produces output.

2.2 Analysis of Collusion[37]

None of the static models of competition in electricity spot markets described above incorporates some potentially important dynamic aspects of competition. However, both theory and experience suggest that the daily repetition of electricity auctions may have a dramatic effect on market performance. In a dynamic setting firms may learn to coordinate their strategies, and hence compete less aggressively with each other over time, through tacit or explicit collusive agreements.

Several authors have pointed out that the frequent interaction between generators which bid daily into the pool creates a favourable environment for tacit collusion. Wolfram (1999) for instance notes that:[38]

> *"A number of attributes of the spot market suggest that the two dominant suppliers could collude to maximise their joint profits. For instance, National Power and PowerGen's daily bids to supply power on the following day are essentially moves in an infinitely repeated game. Also, the fact that the two companies were previously under common ownership would suggest that they have good information about the costs of each others plant and that the lines of communication between them are open."*

Armstrong, Cowan and Vickers (1994) also argue that the repeated nature of the interaction between generators which bid daily into the pool creates a favourable environment for tacit price collusion which may lead to even higher mark-ups of prices over costs than the ones predicted by the static models. To date however, there has been no suggestion that the bidding behaviour of the large thermal generators in the England and Wales pool reveals any clear tendency towards tacit price collusion. In contrast, in the Norwegian and the Spanish electricity market there have been (attempts at) price collusion.[39]

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37 There are few theoretical works which directly apply dynamic models of price competition to consider the scope for collusion in electricity markets. An exception is Fabra (1999) (also Fabra, Harbord and von der Fehr 2000), who analyses the effect of different auction rules on the likelihood of collusion in electricity markets. We omit a detailed discussion of this paper here given that the objectives of that analysis are somewhat tangential to the issue at hand.

38 For similar arguments, see Borenstein and Bushnell (1999), Rothkopf (1999), Fabra (1999) and Klemperer (2000).

39 See Sørgard (1993) and London Economics (1999a).

There are several factors that would appear to make collusion in electricity wholesale markets a particularly significant possibility:

- repeated daily interaction: implying short detection lags which reduce the profitability of defection
- publicly available price bids and capacity declarations: allowing the generators to directly monitor the bidding behaviour of their competitors, and hence to unambiguously detect - and possibly punish - deviations from collusive bidding strategies[40]
- firms have good information about each others' costs: allowing for improved monitoring of each others' actions
- a small number of capacity-constrained bidders: the sustainability of collusion is in general, negatively correlated to the number of firms and the level of firms' capacities

A major factor affecting the extent to which collusion is a viable or sustainable strategy is the number of firms in the market, or the degree of market concentration. This is the philosophy which lies behind the US Department of *Justice's Horizontal Merger Guidelines* (1992) for instance*:*

> *"A merger may diminish competition by enabling the firms selling in the relevant market more likely, more successfully, or more completely to engage in co-ordinated interaction that harms consumers."*

The Horizontal Merger Guidelines make explicit use of concentration indices, as well as other factors, in deciding whether a merger is likely to increase the potential for collusive conduct between the remaining firms in the market. While these of course provide only a rough measure of the extent to which firms in a market are able to exercise market power, they are probably more useful when considering the potential for sustainable collusive agreements to arise, and for two reasons: [41]

- a fortiori, it should be harder to arrange implicit or explicit collusion between a larger number of firms; and
- it becomes increasingly more difficult to identify - particularly in the presence of demand or cost uncertainty - when a collusive agreement is not being adhered to the larger the number of firms in the market

Based largely on empirical studies of price-fixing agreements, Carlton and Perloff (1994) emphasise the importance of the number and the size structure of firms in the market as an indicator of the likelihood of sustainable collusive agreements. Empirically, collusion is most worthwhile in industries with a relatively small

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40 See Harbord (1997) and Cramton and Schwartz (1999) for a discussion of how much information should be revealed to bidders in electricity auctions, and when.

41 Some studies, in particular Compte, Jenny and Rey (1997) and Kühn and Motta (2000), cast some doubt on the use of standard concentration measures, such as the Herfindahl index, to evaluate the impact of asset transfers on the likelihood of collusion.

number of firms protected by high entry barriers. Carlton and Perloff (1994) cite two US studies (Fraas and Greer, 1977; Hay and Kelly, 1974) which indicate that the majority of price-fixing cases prosecuted by the US Department of Justice from 1910-1972 involved fewer than 6 firms, with a typical case involving 4 or fewer firms.[42]

2.3 Contracts, Entry and Investment

Fundamental to the analysis of competition in electricity wholesale markets are the longer-run issues of contracts, entry and investment. Forward contracting is an important feature of all restructured electricity markets, and Newbery (1998)(1999) has emphasised its crucial role as a determinant of entry and investment decisions. The economic analysis of these issues is still relatively undeveloped however, so in this section we briefly review progress to date. Both the supply function and the multi-unit auction models described in the previous section have been extended to account for these issues. The general conclusions of this literature are that:

(i) forward contracting tends to have a procompetitive effect on prices in the spot market, even in the absence of entry;

(ii) long-term contracts increase the effectiveness of entry in disciplining behaviour in the spot market; and

(iii) an increase in the number of competitors reduces prices and increases welfare.

These properties are broadly shared by all of the models which have been used to analyse these issues, and hence are robust to the specific model employed.[43]

The Supply-Function Approach

Newbery (1998) extends the supply function model of the England and Wales electricity spot market to include a contract market, and argues that, when combined with entry, this can have dramatic effects on competition and performance. He models competition in the electricity wholesale market as a two-stage game in which firms first offer a fixed quantity of contracts at a specified price, and then consumers decide whether to accept the contracts on offer. The

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[42] As important as the absolute number of firms is the *degree* of market concentration, *vis*: *"If a few large firms make most of the sales in an industry, and if they can co-ordinate their activities, they can raise price without involving all of the other (smaller) firms in the industry.*" Again the study by Hay and Kelly (1974) verifies this intuition. Some 76% of Department of Justice price-fixing cases from 1963-72 concerned industries in which the "four firm concentration ratio" exceeded 50%.[42] And in 42% of these cases the four firm ration exceeded 75%. Hay and Kelly (1974) also found that most price-fixing conspiracies lasting 10 or more years were in markets in which there were few firms and in which the largest firms made most of the sales.

[43] Wilson (1998) (1999) argues more generally that sequences of forward markets –settled at their own prices – followed by a real time spot market, may provide better incentives and mitigate the market power of generators. See also Cameron and Cramton (1999).

total amount of contracts is revealed, and producers submit supply functions to the spot market. In this framework, Newbery shows that that the effect of contracts is to make the spot market more competitive, i.e. generators are willing to supply a given quantity for a lower price than in the absence of contracts. However, and precisely because of this procompetitive effect, generators may choose not to contract if they assume that their contract positions have no effect on the level of contracts offered by the rivals. Increasing contract cover moves the net supply function to the right; this lowers prices and reduces profits.[44]

More dramatically, however, Newbery (1998) argues that the generation market becomes contestable if entrants can sign long-term, baseload contracts. Using these contracts, potential entrants can lock in future prices and avoid the risk of retaliatory action by the incumbents. The incumbent generators then have an incentive to bid in such a way that the average spot market price is just below the price at which contract-backed entry of IPPs was attractive (i.e. the average total cost of the entrants). This in turn induces the incumbents to sign contracts which mitigate their incentives to raise prices in the pool, thus ensuring that contract and pool prices converge:

> *"Contracts are thus doubly critical for competition. The contract cover reduces the incentive to exercise market power in the pool, while contracts make entry contestable. This gives incumbents an incentive to keep pool prices down, which they can do by selling contracts. … Indeed, the best strategy for entry-deterring duopolists to coordinate on is to choose a level of contracts that maintains the average price just below the entry price... "*

Newbery (1998) also argues that one effect of incumbent generators following this entry-deterring strategy is for incumbents to increase the spread between peak and off-peak prices, thus increasing price volatility in the pool. However as entry occurs, the increase in the number of competitors *"lowers spot price volatility, increases efficiency and raises consumer surplus".* Newbery shows that, for a given aggregate capacity level, when the number of firms is above a critical level, firms will not be able to credibly commit through contracts to prices low enough to deter efficient entry.

The Multi-Unit Auction Approach

von der Fehr and Harbord (1992b) also extended their analysis of spot market competition to include a market for long-term contracts. The analysis identifies a number of important effects that the existence of (options) contracts may have on prices and market performance. In particular they show that there are critical quantities of contracts that must be held by the generators for contracts to have any effect on electricity spot prices. In most cases, when contracts are held in

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[44] Green (1999), on the other hand, shows that if a firm believes that a reduction in its contract cover will be made up by its rival then, for the standard Bertrand reasons, the firm will be selling at marginal cost in both markets and will be willing to cover all of its expected output in the contract market. Powell (1993) argues that if buyers are risk-averse, generators will be able to earn a hedging premium and will then have an incentive to sell contracts.

large enough quantities, the effect is to reduce spot prices to contract prices. This finding is consistent with the evidence presented in Helm and Powell (1993), suggesting a marked increase in pool prices during the spring of 1991 when a proportion of the initial portfolio of contracts expired.[45] von der Fehr and Harbord (1992b) also found that by selling a large quantity of forward contracts, a generator may be able to commit itself to a 'low-pricing, high output' strategy in the pool, thus forcing its rivals to maintain high prices at the expense of their own output. Contracts, therefore, may have a commitment value, and hence be profitable, even if sold for a low price.

von der Fehr and Harbord (1997) analysed oligopoly entry and capacity investment decisions in a decentralised electricity spot market. They considered a two-stage game with multiple technologies and uncertain demand, in which capacity decisions are made prior to spot market competition. This framework is capable of shedding some light on the following questions: Will industry capacity be sufficient to ensure adequate capacity supply? Does imperfect competition in the spot market lead to an inefficient mix of base-load and peak-load capacities? And most important for our current purposes, how does the market structure affect the market outcomes?

von der Fehr and Harbord (1997) considered different assumptions concerning the way in which spot market competition occurs. Under all of these assumptions, aggregate capacities approach their first-best levels as the industry structure becomes sufficiently fragmented. First, they consider the case of a perfectly competitive spot market behaviour, i.e. all units are bid in at marginal cost. In this case there is a tendency towards under-investment whenever capacity choices have a non-negligible effect on market prices. This is for the usual Cournot-type reasons: an increase in capacity lowers the expected spot market price and hence lowers the expected return on the existing capacity units. However, as firms become small - or equivalently, as the industry structure becomes more fragmented - this 'external' effect disappears. As the number of firms grow without bound, equilibrium capacity choices approach the first best.

von der Fehr and Harbord (1997) then characterise equilibrium capacity decisions when there is imperfect competition in the spot market. In a simple case they assume that all firms submit bids which exceed their marginal costs of production by a proportionate amount. They solve examples which show that the equilibrium industry capacity level increases in the number of firms, and that for sufficiently many firms, it is close to the first-best solution. The intuition underlying this result is quite general: the more firms there are in the industry, the greater the probability that a firm will be despatched at full capacity even in cases in which total industry capacity is not fully utilised. Given that investment decisions are based on expected returns, this gives strong incentives for firms to expand their capacities.

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45 Wolfram (1999) finds that the increase in mark-ups associated with the end of the first set of coal contracts in April 1993 is small, but in fact the generators remained heavily contracted after this date.

Table 2.1 below reports the results for the example in which the elasticity of demand is assumed constant. Two observations can readily be made: first, industry capacity is increasing in the number of firms, and second, increasing the number of firms appears to be an effective means of improving capacity investment incentives.[46]

Table 2.1 Industry Capacity as a Percentage of Optimal Capacity

No of Firms	b=v	b=2v	b=3v	b=4v
1	19.1%	19.2%	19.2%	19.2%
2	54.3%	54.8%	54.8%	54.6%
5	80.7%	81.3%	81.5%	81.1%
10	90.2%	91.0%	91.2%	90.8%
25	96.0%	96.9%	97.2%	96.8%
100	99.0%	99.9%	100.2%	99.9%

Note: v denotes marginal costs and b denotes generators' spot market bids.

3 Empirical Analyses and Simulations

While the theoretical analyses described in Section 2 provide important insights into the nature of competition in wholesale electricity spot markets, empirical work is necessary to quantify the importance of the various effects involved. In particular it is of interest to know whether firm behaviour in electricity auctions follows the predictions of the theories, and how rapidly these markets become more competitive as the number of firms operating in them increases. Most attempts to model bidding behaviour in the electricity spot markets have been accompanied by empirical work designed to exploit - or test - the theory (or both). This evidence is discussed in Section 3.1. In addition there have now been a number of attempts to simulate strategic behaviour in these markets, using both

46 von der Fehr and Harbord (1997) also characterise capacity decisions when firms' bids in the spot market result from actual equilibrium behaviour. In this case, whether underinvestment or overinvestment occurs depends on the shape of the demand distribution. However, it is generally true that aggregate capacity approaches the first best level as the industry structure becomes more fragmented. In some cases aggregate capacity is decreasing in the number of firms, and oligopolists overinvest. An increase in the number of firms alleviates this inefficiency by weakening the tendency towards overinvestment in capacity.

very simple and more complex models of electricity spot markets and transmission networks. Section 3.2 summarises the results of these studies.

3.1 Empirical Studies

A standard approach to the empirical analysis of market power in electricity wholesale markets was pioneered in von der Fehr and Harbord (1993) who analysed bid and marginal cost data for the two large thermal generating companies in the England and Wales pool. This approach has subsequently been followed by other researchers such as Wolak and Patrick (1997), Wolfram (1998)(1999a), and Borenstein, Bushnell and Wolak (1999).[47]

von der Fehr and Harbord (1993)

von der Fehr and Harbord (1993) analysed generator costs and bidding behaviour in The England and Wales market from May 1990 to April 1991, using the electricity pool bid data and generator cost estimates derived from published thermal efficiencies and fuel prices. Their evidence showed that for the first 7-9 months of the market's operation, both National Power and PowerGen bid very close to their (estimated) marginal costs in most periods. By early 1991 however, bidding behaviour had changed and both of the thermal generators were increasingly bidding above their costs. They also provided evidence that suggested:

(i) experimentation and abrupt changes in pricing strategies; and

(ii) for at least certain types of units (i.e. large coal sets), asymmetric 'high-low' bidding patterns were emerging - with PowerGen as the high-price bidder - as suggested by the equilibrium analysis

One explanation for the changes in bidding behaviour observed by von der Fehr and Harbord is that for the first year of operation of the new system contract coverage for each generator was approximately 85% of their capacities, and contract strike prices put downward pressure on spot prices. Subsequently contract coverage was reduced, allowing the generators greater freedom to exert market power in the pool.[48]

Wolak and Patrick (1997)

Wolak and Patrick (1997) provided an extensive empirical analysis of prices in the England and Wales pool from 1 April 1991 to 31 March 1995, with a view to assessing whether or not the market had performed competitively. They provided figures on the mean and standard deviation of SMP for the four year period, with each year's pricing data is divided into four demand 'regimes.' They suggested

47 Many of these studies have been described in the survey by von der Fehr and Harbord (1998), and are only briefly discussed here.

48 A second explanation is suggested in von der Fehr and Harbord (1993) which relates the empirical evidence to the results of their theoretical model. More recent support for this has come from the empirical work of Wolak and Patrick (1997).

that these regimes corresponded roughly to those described in von der Fehr and Harbord (1993). They showed that the data was broadly consistent with the hypotheses that:

(i) in low and high demand periods pure strategy equilibria occur, with price being determined by marginal cost bidding in low demand periods, and by at least one generator bidding high prices in high demand periods; and

(ii) in intermediate demand periods only mixed strategy equilibria occur.

Wolak and Patrick (1997) also estimated marginal cost curves for National Power and PowerGen and compare them to bids on selected days in 1995. These comparisons again showed that National Power and PowerGen were bidding well above their (estimated) costs, mirroring fairly closely the results of von der Fehr and Harbord (1993).

Wolfram (1999a)

Wolfram (1999a) applied three techniques from empirical industrial organisation theory to the measurement of market power in the England and Wales electricity spot market from 1992-1994. She found that prices were on average 25% above the costs of the last plant needed to generate electricity in a given period. She first constructed industry-level marginal cost curves and computed the industry price cost margin.[49] She then used two NEIO ('new empirical industrial organisation') approaches to measuring market power. The first technique exploits the distortion in the generators' pricing behaviour induced by changes in the regulatory environment to measure the extent to which firms were able to increase their bid prices above costs. The second technique identifies the price-cost margins by changes in demand.[50] The results of all of these approaches are broadly similar. Wolfram found price-cost mark-ups around 25%, but also concluded that the generators were not exercising their market power to the degree predicted by the theoretical models. This was explained first by contracts, and later by the imposition of a price cap on pool prices.[51]

Wolfram (1998)

Wolfram (1998) analyses bidding behaviour in the England and Wales pool based on a theoretical framework roughly corresponding to the multi-unit auction approach of von der Fehr and Harbord (1993) (and based more generally on insights from Ausubel and Cramton, 1997). She considers an independent private-values multi-unit auction in which generators have perfect information

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49 Based on assumed fuel prices and operating efficiencies of each generating plant.

50 Baker and Bresnahan (1992) describe these techniques.

51 Wolfram (1999) also hypothesised that the threat of entry may be constraining pool prices, following Green and Newbery (1992) and Newbery (1998).

concerning costs,[52] and focuses on the incentives of one firm to alter its price bid for a given plant, given the equilibrium bids of its rival. She attempts to identify the factors which determine a firm's incentives to increase its bids above its cost. Wolfram notes that whenever there is a positive probability that a firm's bid will be marginal, then the firm has an incentive to increase its bid in order to increase the revenues earned on its inframarginal capacity.[53] The greater a firm's inframarginal capacity, the more profitable such a strategy will tend to be, and hence the greater the incentive to bid prices above marginal costs. Such an incentive is tempered, however, by the fact that bidding higher prices reduces the likelihood that the firm's bid will be marginal. Finally, Wolfram argues that the expected mark-ups are a decreasing function of the unit's size, since the loss from having the unit excluded from the market is greater for larger units.

By the same argument, a small firm with little or no inframarginal capacity will have much less incentive to submit bids above its marginal costs. Bidding above marginal cost will increase its revenues in the event that it is despatched at the margin (thus setting system marginal price), but this is offset by the risk of its capacity being excluded from the market altogether. Both large and small firms face exactly the same 'downside' risk from increasing their bid on the marginal unit; the larger firm however weighs this against a much greater 'upside' gain - *vis.* the extra profits earned on its inframarginal units.[54]

The purpose of Wolfram's (1998) empirical analysis is to test the applicability of this intuition, drawn from the multi-unit auction analysis, against the market data. Her analysis focuses on the bidding behaviour of the largest generators in England and Wales, National Power and PowerGen, between 1992 and 1994,[55] and she obtains the following results:

- the largest participant in the market (National Power) submitted higher price bids than its smaller competitor (PowerGen) for units with comparable costs;

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52 But faced uncertainly about the capacity bids of their competitors. This uncertainty may derive from private information about the availability of a competitor's plant on a given day, for instance.

53 See the discussion of Proposition 1 in von der Fehr and Harbord (1993) where this intuition is explained in greater detail.

54 As noted above, Wolfram also calculates mixed strategy equilibrium distributions for asymmetrically sized generators, using a similar set-up as von der Fehr and Harbord (1993). Here she shows formally that a generator with more inframarginal capacity will submit higher bids, and that the incentive to submit higher bids is increasing in the amount of inframarginal capacity it owns. Hence she predicts that larger firms will be more frequently observed submitting bids which significantly exceed their marginal costs in the England and Wales electricity market than smaller firms.

55 Wolfram justifies the exclusion of other firms from the empirical analyses on the grounds that the bids submitted by Nuclear Electric were dictated by the operating requirements of nuclear power plants, and were frequently zero.

- generators submit bids reflecting a larger mark-up over marginal costs for plants that are likely to be used in periods when the firm's inframarginal capacity is larger;
- generators submit higher bids for given plants on days in which more of its plant is available; and
- the incentive to set a high price for inframarginal capacity is moderated by the incentive to ensure that a unit is not left out of the despatch schedule

Wolfram notes that these results are consistent with Newbery (1992), who predicts that the larger supplier submits prices reflecting larger mark-ups above its marginal costs than the smaller supplier.

Borenstein, Bushnell and Wolak (1999)

Borenstein, Bushnell and Wolak (1999) provide evidence for the exercise of market power in California's wholesale electricity market during June-November 1998. Using a similar approach to Wolfram (1998), they estimate the extent to which California wholesale electricity prices have exceeded competitive levels. They find a 29% increase in the total cost of power due to the exercise of market power.

Borenstein, Bushnell and Wolak (1999) base their diagnosis of market power on the comparison between the actual energy prices[56] in a given hour and their estimates of the prices that would arise in a competitive market. In a given hour, the intersection between the estimated industry-level marginal cost curve and the residual demand curve[57] provides an estimate of system marginal cost in a competitive market, and the market clearing quantity. By comparing these to the actual observed outcomes, they show that the incidence of market power is much larger in peak as compared to off-peak periods.[58] The ratio between the added cost of energy due to market power and the total cost of energy was estimated at 48% and 58% during the peak months of July and August respectively. In contrast, during off-peak periods these ratios are very low (even negative). The average value of the ratio for the entire period of their study is 22.4%.

Discussion

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56 Borenstein, Bushnell and Wolak (1999) rely upon the unconstrained Power Exchange (PX) day-ahead energy price as their estimate of energy prices. The California electricity market consists of several parallel markets. However, given that market participants are free to participate in any of these markets, one would expect the average of the market clearing prices in all these markets to be equal in expectation.

57 The residual demand curve is equal to the actual metered generation and imports for a given hour plus the addition to demand due to the need for capacity regulation, minus the demand satisfied by the must-run resources, the hydro and the geothermal resources, and the imported energy adjusted by the market clearing prices.

58 Peak periods include the higher demand months of July and August and the higher demand hours; off-peak periods include many hours in the month of June and the off-peak hours, 1-6, in the later months.

Empirical studies provide abundant evidence for the proposition that market power has been exercised in the restructured electricity markets in Britain and in California. They also provide evidence to support the theoretical analyses of bidding strategies described in Section 2.1. In particular, market power is typically exercised in high or variable demand periods, and larger firms tend to submit higher bids than their smaller rivals. The empirical studies have been so far limited, however, to analysing the experience of one or two highly concentrated markets The advantage of the simulation or experimental studies discussed immediately below is that they can directly address the relationship between market power and market concentration.

3.2 Simulation Studies and Experimental Approaches

A number of studies which simulate strategic behaviour in electricity wholesale markets now exist, using both very simple and more complex models of electricity auctions and transmission networks. Following the early 'small-scale' simulations of Green and Newbery (1992) and Lucas and Taylor (1993), Harbord and von der Fehr (1995) undertook the first large-scale simulation study of the potential for the exercise of market power in a wholesale electricity market for the Industry Commission of Australia. A number of researchers have since taken up this approach, including Borenstein and Bushnell (1998) and Borenstein, Bushnell and Knittel (1999). Weiss (1998) takes a different approach by performing market experiments, which we also report on below. [59]

Simulation of the Supply Function Model

Green and Newbery (1992) calibrated their supply function model to the circumstances of the E&W industry using demand, output and cost data from 1988/89. Their result for their 'no entry' case, using a demand slope parameter of 0.25, was that in the highest-price, static, symmetric, duopoly supply-function equilibrium, the energy price was approximately 80% higher than the 'perfectly competitive' price level, and output was 10% lower. When a more 'vertical' demand curve was assumed, the average pool price was significantly higher, but output remained roughly constant. With five equally sized generators however, they found that the average equilibrium price would have been £27 per MWh, much closer to the competitive outcome.

Green and Newbery also analysed their model for the case of asymmetric duopoly, with one larger and one smaller generator, and found that the differences at the industry level between the symmetric and asymmetric equilibria were small. In the asymmetric case however, the larger generator ('National Power') stood to gain relatively more from keeping prices high and so submitted a

[59] Again, many of the earlier studies have been previously described in detail in von der Fehr and Harbord (1998), and are only discussed briefly here.

steeper price schedule. As a result - and unlike their symmetric case - they found productive as well as allocative inefficiency.[60]

Finally, Green and Newbery considered the entry by new generators into the market, assuming that entrants all built CCGTs. They assumed that entry would occur until the average pool price equalled the entrants' average energy costs (approx. £30 per MWh). On these assumptions their base case predicted an additional 8 GW of capacity being added to the market, lowering average pool prices but resulting in a good deal of excess capacity, and hence adding to welfare losses.

Green and Newbery's most well-known prediction however was that if the CEGB's generation capacity had been divided into five equally sized firms, as was originally planned, something much closer to competitive outcomes would have resulted. In short, their supply function model simulations show a strong and highly significant correlation between market concentration and market performance.

The Australian Market Power Study

A larger-scale simulation of generator bidding behaviour in the Australian National Electricity Market, based on the model of von der Fehr and Harbord (1993), was undertaken for the Industry Commission of Australia by Harbord and von der Fehr (1995). The purpose of the study was to analyse likely bidding behaviour by generators in the interconnected state electricity markets under different assumptions concerning the horizontal structure of generation. At issue was whether Pacific Power - New South Wale's monopoly, and Australia's largest, generator - should be left intact as a single generating entity, or split up into two or more separate companies. In order to do so a computer model of the Australian electricity market was employed to evaluate payoffs to generators for different bidding strategy combinations, and this model was amongst the most comprehensive, detailed and realistic available anywhere. The study made use of an actual model of the Australian system - including the pool price setting mechanism, generator capacity and cost data, and transmission and interconnector constraints, to assess the effects on generator bidding behaviour and market prices of different market structures of generation. Therefore the effects of different types of bidding behaviour on generator payoffs could be evaluated in a reasonably realistic setting.

Figure 3.1 describes the basic market structure of the Australian electricity industry in July 1995. In New South Wales, peak demand of 9500 MW was met by 12,400 MW of capacity controlled by Pacific Power, the state monopoly utility. Victoria had a peak demand of 6000 MW and capacity of 7,900 MW. In South Australia the corresponding figures were 1600 and 2900 respectively. In addition the Snowy Mountain Hydro Authority had a capacity of 3700 MW, which was sent

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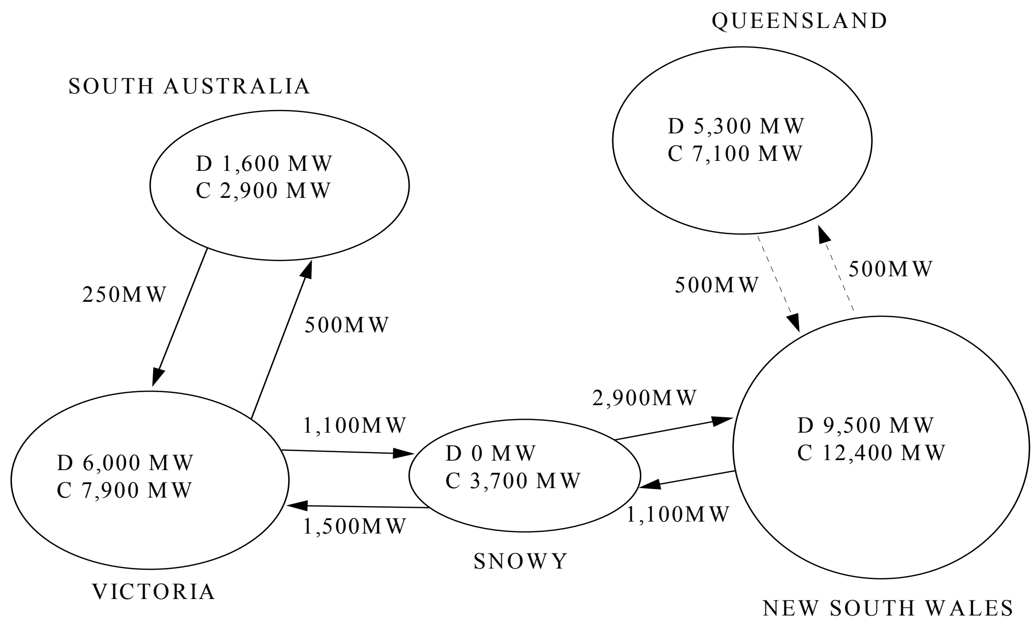
60 That is, overall industry supply costs were not minimised because the merit order was distorted, with some cheaper 'National Power 'plant being bid in at higher prices than more expensive 'PowerGen' plant.

via interconnects to both Victoria and NSW. The capacities of the interstate interconnectors are also shown in Figure 3.1. As is evident, interconnector capacities were small relative to the within-state generation capacities. This is particularly so for South Australia, where imports and exports capacities amounted to, respectively, 18% and 9% of total generation capacity. The import capacity to New South Wales was approximately 23% of the state's generation capacity.

Figure 3.1 The Australian National Electricity Market, 1995



In 1995 Pacific Power had 48% of the total system capacity within the interconnected south east region of Australia. In contrast, Victoria had separated its generation sector into five entities, two of which had been privatised, and the largest of which had a generating capacity of 2000MW, representing some 8% of total interconnected system capacity. The South Australian utility had 9% of interconnected system operating capacity.

The study addressed the issue of the likely competitiveness of generator bidding behaviour in the National Electricity Market under two basic options for generation structure:

- Pacific Power as a single entity, and

- Pacific Power broken up into two or three (more or less) equally-sized, independent companies

The model used solved for system marginal price (SMP) in each regional market, output and operating profits for each generating unit, and power flows (including those over the interconnects) for any given set of strategies assumed for the generators. In each game modelled, strategic players were allowed a choice between three different step supply function bidding strategies - marginal cost bidding, twice marginal cost bidding, and three times marginal cost bidding. Simulations were undertaken for six different day types.

Pacific Power as a single entity

The typical result in all simulations with a single New South Wales generator was that Pacific Power had a dominant strategy to bid at the highest multiple of marginal cost permitted (three times marginal cost in this example). This result was robust to changes in modelling assumptions and day types, and also survived increasing the size of the interconnect links between states, and allowing for a significant amount of IPP ('independent power producers') entry. The reason for this was evidently that its share of New South Wales and south east Australian generation capacity meant that Pacific Power was the residual monopolist in all scenarios, and priced its capacity units accordingly.[61]

Table 3.1 illustrates a payoff matrix for a cold business day (i.e. medium demand day) in which the two strategic players are Pacific Power as a single entity, and the South Australian generator.

Table 3.1 PP versus SA: Dominant Strategy Equilibrium

Cold Business Day	**PP = MC**	**PP = MC*3**
SA = MC	$57,$269	$364, $4,258
SA = MC*3	$784, $430	$784, $4,375

Three-part Pacific Power

All other simulations carried out assumed Pacific Power broken up into two or three entities. The former resulted in little improvement in the outcomes. The simulation results for the three-part Pacific Power differed dramatically from the previous simulations however. On low demand days (e.g. 'mild non-business days') each of the three former Pacific Power generating entities bid at marginal cost in equilibrium, and thus very competitive outcomes emerged. On high demand days (e.g. 'hot business days') there were multiple equilibria, in each of which one of the former Pacific Power generators bid a high price (i.e. at the

61 Under this market structure for generation the von der Fehr and Harbord (1993) model would predict a high-low bidding equilibrium outcome, with Pacific Power as the high bidder. Since, by assumption, in these simulations the Victorian generators bid at marginal costs, this is exactly the type of outcome that is found here. The five small Victorian generators were assumed to bid at marginal cost in most runs, however the robustness of this assumption was checked.

maximum multiple of marginal cost allowed), while the other two firms bid low at marginal cost. Hence although the bidding strategies now reflected strategic considerations on high demand days, high priced outcomes still resulted in some of the simulations on some day types. In fact perfectly competitive outcomes occurred in fewer than half of the six day types. Nevertheless average market outcomes were significantly improved by the break-up of Pacific Power into three parts, and average annual pool prices fell by more than 20%.[62]

Easing transmission constraints

Two alternatives for increasing the size of interstate links were considered in the study. The first assumed strengthening of the existing interconnector links by 30%. The second assumed that the interconnector to Queensland had been constructed. Neither option had any significant effect on system marginal prices under any scenario. It remained a dominant strategy for Pacific Power to bid at the highest allowed multiple of marginal cost. The conclusion was therefore that increasing interconnection capacities, or the construction of Eastlink, did not appear to reduce Pacific Power's monopoly power.

Entry by IPPs

An alternative way of bringing more supply capacity, and hence competition, into the New South Wales market was by the entry of new, independent generators. This was simulated in two experiments in which 800MW and 2800MW of independent generation capacity were added respectively to the New South Wales market.[63] This IPP capacity was assumed to have marginal costs of \$25/MWh to \$26/MWh, and to bid at this level. The effect was that Pacific Power's profits fell by approximately 40%, but that average pool prices remained almost identical to the no entry case. Therefore from the consumers point of view, new IPP entry on this scale had almost no significant effects. Indeed, constructing costly, new capacity was highly inefficient since it increased the amount of excess capacity in the market, without significantly affecting either total output or market prices.

Concluding comments

The Australian public policy debate concerning whether Pacific Power should be left intact to operate as a single entity in the national electricity market, or broken up into a number of competing units, was unique at the time, not least because it attempted to address directly issues of market structure and competition which had been largely neglected in electricity market reforms elsewhere. The debate was able to draw upon international experience with previous (not entirely successful) reforms, a burgeoning theoretical and empirical literature on

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62 Given the size of each of the three Pacific Power generators relative to the within-day variation in demand in New South Wales, the von der Fehr and Harbord model would predict that no pure strategy equilibrium exists in this game (see Section 2.1 above). Choosing a randomised strategy was not an option in the simulations however.

63 The latter case increased New South Wales capacity by over 20%.

competition in electricity pools, and empirical techniques and models which have been unavailable to study these issues hitherto.

As noted, a computer model of the Australian electricity market was employed to evaluate payoffs to generators under for different bidding strategies. This model contained a detailed and realistic representation of the Australian pool price-setting mechanism, generator capacity and cost data, and transmission and interconnector constraints. Therefore the effects of different types of bidding behaviour on generator payoffs could be evaluated in a reasonably realistic setting.

The main conclusion of the study was that *market structure was the primary determinant of market performance*, despite claims made to the contrary by opponents of the reforms. Forcing the break-up on Pacific Power into at lest three separate companies was shown to have a much greater effects on market prices and firms' profits than any of the other measures which had been suggested, such as increasing transmission capacity. In August 1995 the government-appointed New South Wales Generation Reform Working Group recommended the break-up of Pacific Power, and this subsequently became government policy.[64]

Cournot Simulations: Borenstein and Bushnell (1998)

Borenstein and Bushnell (1998) undertook a Cournot analysis of the potential for competition in the deregulated California electricity market. They simulated competition in the market using historic data, and found that in the presence of transmission constraints between northern and southern California, the availability of hydro capacity, and the elasticity of demand were crucial determinants of the potential for market power problems to arise. Their simulations also clearly showed that a divestiture of gas fired stations by the two dominant Californian generators would significantly lower prices and reduce deadweight losses, at least under Cournot assumptions.

Borenstein and Bushnell (1998) modelled the two largest California generators – Pacific Gas and Electric (PG&E) and Southern California Edison(SCE) – each with market shares in capacity terms in excess of 40%, as strategic Cournot players. They also included a smaller generator, San Diego Gas and Electric (SDGE), with a less than 10% market share, as a strategic Cournot player.[65] They then examined firm-by-firm hourly output levels for different months in a 'base case' with a demand elasticity equal to 0.1. The three highest demand hours modelled produced significant price mark-ups. The Cournot equilibrium price in the next highest demand hour was by comparison only marginally above the perfectly competitive price level for that hour. These price differences were largely

[64] The Working Group's key recommendation was that Pacific Power be broken up into two units, for reasons of 'financial viability.' However for reasons well outside the domain of the current discussion, the ultimate result was that three new independent generators were created.

[65] As we point out below, this firm nevertheless behaved as a 'price-taker'.

driven by the elasticity of fringe supply. In the peak hours the two dominant Cournot firms reduced their output while the fringe firms (and the smaller Cournot player) utilised nearly all of their capacity. When the fringe's capacity was exhausted this allowed the dominant Cournot firms to significantly increase price by reducing output. In lower demand hours, fringe production was the marginal output, and the Cournot firms had much less incentive to withhold production.

Significantly the small Cournot player SDG&E, did not behave like its larger rivals (see Borenstein and Bushnell, 1998, Table 5, partially reproduced below). It increased its output in peak demand periods and reduced its output uniformly in lower demand periods. In effect, this smaller firm acted as a competitive 'price-taker,' adjusting its output upwards when the dominant players reduced theirs and visa versa.

Table 3.2 Simulation Results for December Base Case[66]

DEMAND LEVEL	Peak	150th highest	300th highest	450th highest	600th highest	744th highest
Competitive Price ($/MWh)	34.01	28.73	28.82	26.98	25.76	25.16
Price ($/MWh)	421.22	150.88	137.58	28.13	8.06	25.42
Mkt Quantity MW	37454	35703	33960	32661	28113	24380
PGE Quantity	5118	4261	4060	7579	5593	4694
SCE Total Quantity	6545	5682	5480	8100	4588	4542
LADWP Total Quantity	6138	6138	4891	4147	4147	2183
SDGE Total Quantity	2253	2207	2114	1045	741	378
Cal Fringe Total Quantity	11004	10971	10971	9351	9419	8654
SW Fringe Total Quantity	6056	6056	6056	2439	3625	3861
Mexico Fringe Total Quantity	340	388	388	0	0	68

Note: Cournot quantity choices of PG&E, SCE, and SDG&E include only fossil and hydro production.

Borenstein and Bushnell calculated hourly market shares for Cournot firms, defined as total firm output divided by market output. They then calculated the Lerner index as the mark-up over the competitive price resulting from the Cournot simulations. The concentration measures thus calculated (HHIs),[67] and the price-cost mark-up, did not, according to their simulations, exhibit a systematic correlation. In other words, the degree of market concentration was not a good predictor of the periods in which market power was exercised.[68]

Divestiture of gas-fired generation

Borenstein and Bushnell also examined possible divestiture options. The first option spun off all of SCE's gas units and half of PG&E's into three firms. They labelled this option 'partial divest'. The second option divided the gas-fired PG&E

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66 Partial reproduction of Borenstein and Bushnell (1998) Table V.

67 The HHI – or Hirschmann-Herfindahl Index - is the sum of the square of each firm's market share times 10,000.

68 It is crucial to note however that this is because the HHIs were calculated using firms' outputs in the Cournot equilibrium rather than their capacities. When prices were high this was induced by Cournot firms reducing their outputs relative to the 'fringe', hence the concentration measure decreased. This is, of course, arguably a questionable, if not quite novel, use of concentration measures. This issue is discussed below.

and SCE stations amongst seven firms. This option was referred to as 'full divest'. The effect of each of these divestiture options for September on Cournot equilibrium prices was calculated.

The change in peak prices in comparison to the no divestiture case was substantial, even when the units are only partially divested to 'Cournot' firms. For an elasticity of 0.1, *prices in the peak demand hour of September dropped 91% under the partial divestiture scenario and 96% under 'full' divestiture*. They also calculated the effects of the partial divestiture option on consumer surplus and overall dead-weight losses. During the peak hours (of September) partial divestiture increased consumer surplus by about $183.6 million compared to the base case, of which about $165.9 million was a transfer from producers, and the remaining $17.7 million represented a reduction in dead-weight loss.

Summary of Borenstein-Bushnell analysis

Despite their conclusions that factors other than market concentration are important to market performance, reduction in industry concentration in their study, as in the studies of Green and Newbery and Harbord and von der Fehr (1995), resulted in a significant reduction in prices and increases in overall welfare. Indeed, according to Borenstein, Bushnell and Knittel (1999):

> *"Originally, the two largest investor owned utilities in California, Pacific Gas and Electric and Southern California Edison, were pressed to divest one-half of their gas-fired generation capacity. Although this original divestiture did have a significant impact on the equilibrium prices in our model, the potential for substantial market power still remained. Eventually, both PG&E and SCE announced plans to sell off all of their gas-fired generation. … The generation capacity of these two formerly dominant firms has now been divided into 8 highly decentralized generation portfolios. The impact of these additional divestitures on equilibrium prices is significant. [Our] results illustrate that the current divestiture proposal is likely to have a far greater impact on equilibrium prices in the California market than the original proposal. Although, there still remain demand levels where market power can be a problem, the threshold value where this is likely to occur is far greater under the current divestiture plan, relative to the original proposal."*[69]

Borenstein, Bushnell and Knittel (1999) also make it clear that their counterintuitive results on concentration measures derive from using hourly output, rather than capacity measures, of firms' market shares. Indeed they admit to there being a measure of irony in their findings:

> *"At the higher demand levels, many producers reach their full output capacities. The disciplining effect of those producers on strategic behavior*

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69 Joskow (2000) confirms that post-divestiture, the California market has become significantly more competitive. That higher prices are still occurring in peak demand periods is not surprising given that PG&E retains in excess of 30% of market capacity and SCE in excess of 16% of market capacity.

> *by the remaining firms therefore is severely reduced. These remaining producers can profitably reduce their output, knowing that most of their capacity-constrained competitors will be unable to respond with increased production. Ironically, when such behavior occurs, the concentration of the market appears to be reduced, since the strategic firms – the largest producers – are in fact withholding production, and therefore reducing their market share. We found many cases in which the price-cost margin increased as concentration declined."*

Since Borenstein, Bushnell (and Knittel) have repeatedly suggested that their analysis demonstrates the inapplicability of concentration measures to deregulated electricity markets, it is worth spelling out again why this argument would appear to be specious. First, their simulations show that 'small' firms such as SDG&E, even when explicitly modelled as 'strategic' Cournot players, act instead as competitive price-takers.

Second, they estimate market concentration (HHIs) using the firms' simulated hourly outputs. This leads to the apparently perverse conclusion that prices may fall as market concentration increases, because in high demand periods the large strategic firms reduce their output in order to increase market prices. This is a feature not only of the Cournot analysis, but also of the multi-unit auction models of electricity wholesale markets described above. *Hence there is no reason at all to expect a positive correlation between market concentration, measured hour by hour on the basis of outputs, and market prices - indeed quite the reverse*.[70]

All of this simply tells us what most economists already know. A mechanical approach to the measurement of market shares, uninformed by an appropriate equilibrium analysis of competition in the market, has the potential to lead regulators and competition authorities badly astray. Concentration measures based on firms' capacities, or output measures taken over longer periods of time, would not exhibit this feature.

The US Department of Energy Study

Gruenspecht and Terry (2000) reports on simulations of U.S. regional power markets using the Department of Energy's Policy Office Electricity Modeling

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[70] To see why this approach to using concentration measures is particularly subject to perverse results, consider a game of 'capacity constrained Bertrand price competition' between two duopolist producers, with a competitive fringe. As is well known, pure strategy equilibria will not typically exist, so the duopolist firms will randomise over a price interval bounded below by their marginal costs and above by the Cournot prices for the residual (i.e. net of fringe production) demand curve. (See Armstrong, Cowan and Vickers, 1994, Ch. 9, for a description; Kreps and Scheinkman, 1983 and Davidson and Deneckere, 1986 for more details). In some periods, both duopolists will randomly choose to offer low prices, and sell more output, whilst in other periods both will randomly offer high prices and sell less output. It is not unlikely that concentration would then be measured as 'high' in low price periods, and 'low' in high price periods. This is not a particular feature of electricity markets, rather simply a consequence of taking a naïve approach to the use of concentration indices in order to measure the period-by-period exercise of market power.

System (POEMS).[71] The analysis showed that market power could be profitably exploited in some parts of the United States in markets where concentration is high and transmission constraints impede imports of power from distant generators. The authors found in particular that, *"…large firms can employ a simple market power bidding strategy to cut output and increase net revenues from generation by driving up the market price of electricity."*

The POEMS model was used to simulate a simple bidding strategy which involved increasing bids of plants in the middle of the despatch order — so-called 'mid-merit' plants —to 150 percent of the competitive level. To examine the potential for the exercise of market power in restructured electricity markets, the data-base supporting POEMS was searched to identify groups of firms with 'high' and 'low to modest' potential to exercise market power, based on concentration and transmission capacity information. Four to five companies in each category were identified according to the criteria given immediately below. In addition to physical transmission capability, the organisation and pricing structure of transmission markets was also taken into account, since these were presumed to affect the ability of 'outside' generators to compete with generators within a given region.

The criteria used to identify firms with 'high' and 'low to modest' potential to exercise market power, based on concentration data and transmission capacity information, were as follows:

- *High Market Power Potential:* A single company owning more than 75% of the capacity in the power control area (PCA) with transmission import capability into the PCA of less than 40% of the company's capacity.[72]
- *Low to Modest Market Power Potential:* Any company owning 20% to 50% of the capacity in the power control area (PCA) with transmission import capability into the PCA of over 100% of the company's capacity.

The results of the simulations, reported in greater detail in Gruenspecht and Terry (2000), may be summarised as follows:

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71 POEMS is a modeling system that integrates the Energy Information administration's National Energy Modeling System (NEMS) with TRADELEX, which provides a much more detailed representation of electricity markets than the NEMS electricity module. For a description, application, and documentation of POEMS see U.S. Department of Energy, Office of Policy (1999).

72 Members of the high market power potential group were selected by applying these criteria to investor-owned utilities (IOUs) in the 20 regions into which the US's 140+ power control areas and 3,000+ utilities are assigned for purposes of reporting POEMS results. Then all IOUs meeting these criteria were sorted by generation capacity and region. The four largest of these utilities (subject to a limitation of one per region) were included in the sample. One smaller firm with a dominant position in a region with smaller load was added to the group to avoid an exclusive focus on larger markets.

Result 1: None of the firms in the low market power potential group were able to raise their profitability by bidding their mid-merit units at 150 percent of the competitive bids. They lost more in operating surplus (revenues minus variable costs) from not running these units during periods when the market price fell between 100 percent and 150 percent of the competitive bid than they gained from the impact of their bidding strategy on prices.

Higher bids by firms with low-to-modest market power potential increased wholesale electricity prices in the relevant PCAs by 2 to 9 percent, and the hence other companies in the PCA benefited from the receipt of higher revenues. However all of the companies in this group lost a significant share of generation and were made worse off as a result of attempting to exercise market power.

Result 2: Firms with high potential market power can generally increase their profits by exercising their market power to raise prices. Operating surpluses for the six companies in the high market power potential group increased by 25 to 75 percent, and wholesale prices within the PCAs of each of the firms rose by 8 to 30 percent when the firms applied a strategy of bidding their mid-merit units at 150 percent of the competitive bid.

Each of the firms in the group with high market power potential benefited from raising its bid price. The increase in the market-clearing price more than offset the loss of revenue due to decreases in output. Altogether, the five generators chosen in the study earned an additional $800 million in operating surplus, and wholesale prices within each of the PCAs rose by 8 to 30 percent as a result. For most of these firms, increasing the bid price of selected plants was profitable in virtually all time periods. In other words, at each level of demand, the effect of the increase in price more than offset any loss in generation.

Result 3: The impact of higher prices due to market power exercised by large firms was felt across a wide region and benefited many firms. The increase in operating surplus flowing to all generators as a result was more than twice the amount earned by only those plants exercising market power.

Result 4: New entry by other firms eases market power over time.

Because the exercise of market power was driven by dominance in an area by one or a few players, a region could alleviate a potential market power problem through entry by other firms.

Result 5: The potential to exploit market power in restructured electricity markets increases if restructuring does not include provisions that increase the efficiency of transmission markets.

The results summarised above were derived from model runs in which transmission prices were determined through a 'postage stamp' system, under which generators pay a flat fee to wheel power anywhere within the network regardless of the distance travelled. To assess the influence of transmission pricing on market power, the scenarios were re-run assuming 'pancaked' rates, under which fees are paid to each transmission owner along the contract path. Although transmission rates are the same in both scenarios, the total amount of transmission fees paid by wholesale market participants was higher in this scenario because of the pancaked rate structure (assuming the volume of wholesale wheeling remains unchanged). The additional fees raise the cost of wheeling power across more than one utility system and effectively reduce the geographic scope of several regional markets.

Three of the firms in the 'high market power potential' group were able to exploit their market power more effectively under pancaked rates. Although, as in the previous scenario, each firm bids 150 percent of its marginal cost, the pancaked transmission fees increased the cost of importing power, allowing generators to raise prices without losing significant market share.

Weiss (1998)

There have been relatively few experiments of wholesale electricity markets. Experiments by Acton and Besen (1987) and by Hahn and Van Boening (1990) address issues within a regulated electric utility framework and are hence of little relevance to the questions addressed here. Bakerman, Denton, Rassenti and Smith (1997) and Bakerman, Rassenti and Smith (1997) present results from experiments with a similar focus on market power.[73]

Weiss' experiments differ from previous electricity market experiments in two important ways: They included a more accurate representation of the electric transmission network than other experiments, and they make use of experienced industry subjects only, rather than undergraduate or graduate students. Accurate modelling of the transmission network makes the experiments considerably more complex, but it allowed an investigation of some of the characteristics of electricity markets not shared with other markets. In particular, the concept of nodal pricing as well as the concept of uplift in the England and Wales spot market can only be studied at the level of complexity considered in these experiments.

Description of the experimental design

Buyers and sellers in the experiment were located at different nodes of a simple network of transmission lines. The electric network modelled was a simplified version of a real electricity network. There were 1300 MW of generation capacity distributed equally amongst all sellers, and located at four transmission nodes connected through five transmission lines. A competitive fringe owned an additional 400 MW of capacity through four plants with 100 MW capacity each. Competitive fringe plants always bid at marginal cost. The remaining 900 MW of capacity were equally distributed amongst all players: In environments with one and three sellers, the 900 MW of capacity were split into nine power plants of equal capacity, with each player owning an equal share. In environments with six sellers, the same 900 MW were split into 18 power plants of 50 MW capacity each, with each player again being assigned three plants.

Two buyers were located at different nodes. Each buyer was to serve three demand segments of varying size and value. Transmission capacity of the lines

[73] Because of some special features of their experiments reported in the footnote below, we have not described them in detail here.

connecting the four nodes was unlimited, except in the case of the line connecting nodes b and d. The transmission limit on that line was 100 MW during the first 23 rounds of the game, and unlimited thereafter. All lines were assumed to have the same length and physical properties (resistance, reactance).

The market was organised as a sealed bid, first-price auction. All bids and offers were posted simultaneously, and market prices were determined by the intersection of bid and offer curves. No bilateral transactions between individual players were allowed. In both pricing environments, i.e. nodal and uniform pricing, an independent system operator (ISO) played the role of the market clearinghouse and used the bids provided to decide on the optimal pattern of load and generation.

All power plants in the experiments had constant variable costs over the entire range of output and had the same capacity.[74] Wholesale buyers could resell the electricity bought in the market to three customer groups: residential customers, commercial establishments, and industrial customers, at fixed prices. A substantial part of demand from the largest customer group was 'must-serve' load. Not buying enough power to serve all must-serve load resulted in a severe penalty for buyers. The portion of must-serve load represented 75% of total demand during high demand, 72% during medium demand, and 67% during low demand. [75]

The 180 participants in the experiments were recruited via email advertisements to individuals associated with the electricity industry. Addressees were told that they could gain insights into the workings of competitive electricity markets, and that they could win a prize of $2,000.

Experiment results

Further details of these experiments are reported in Weiss (1998). We limit ourselves here to summarising the main results. As reported by the author:

> *"Our experiments provide some interesting and new results relating the design of electricity markets to the potential exercise of market power. We find that the standard solution for decreasing market power, an increase in the number of sellers competing in the total market… may not be sufficient*

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74 Plants A,E, and I differed from the other plants by a penalty incurred if they were not at least partially despatched. This penalty was created to reflect the must-run character of many base load plants in real electricity markets.

75 One major difference between these and previous electricity market experiments lies in the modeling of the transmission system. Most previous experiments in this area have either not modeled transmission at all, or, as Bakerman, Denton, Rassenti and Smith (1997) and Bakerman, Rassenti and Smith (1997) have used a simple three node radial network in which some of the interesting features of real world transmission systems, in particular loop flows, do not exist. Loop flows are the source of important network externalities. Loop flows and transmission constraints make it necessary to deal with constrained-on/off plants and customers. Therefore not all relevant properties of deregulated electricity markets can be observed in laboratory settings which exclude loop flows.

> *to lower prices at all market locations if transmission capacity is limited. Rather, local market power persists at some locations. While an expansion of the transmission system will remove such local market power, we find that demand side bidding may be an equally powerful market power mitigation strategy, in particular in a system of nodal prices. We also find that institutional detail such as the pricing mechanism has important implications for the distribution of rents among buyers and sellers, as well as for the sources of and remedies for market power. Our experiments confirm the notion that markets become more competitive in the sense that overall efficiency increases and that the share of social surplus available for distribution between buyers and sellers is split more evenly as seller concentration decreases."*[76]

Weiss's findings therefore support those suggesting divestiture as the main market power mitigation strategy in deregulated power markets. The qualification is that in nodal price environments, prices at some nodes, remain high even as the market concentration is significantly reduced. This confirms the well-understood notion that individual plants or firms may have local market power, depending on their location relative to demand centres and transmission bottlenecks, as suggested by the models of Nasser (1997) and Cardell, Hitt, and Hogan (1998).

Weiss found that an effective mechanism for lowering high nodal prices, and thus for mitigating local market power was the active bidding for power by a small number of buyers on the demand side of the market. This finding tends to confirm the importance of demand side bidding found by Bakerman, Denton, Rassenti and Smith (1997) in their somewhat simpler radial network design, and by Borenstein and Bushnell (1998) in their simulations. He therefore recommends policy measures aimed both at increasing the demand elasticity through technology and at increasing the bargaining power of the demand side by allowing active participation of concentrated intermediate buyers.[77]

In a uniform-price environment, as used in the British electricity spot market, Weiss's experiments tend to confirm Wolak and Patrick's (1997) result that firms in the market have an incentive to alter their bids so as to maximise payments received for their plants through capacity payments. He suggests (tellingly) that

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[76] This finding differs from the results obtained by Bakerman, Denton, Rassenti and Smith (1997), who find that decreasing seller concentration has no significant impact on price levels or market efficiency. Bakerman et al. attribute their counter-intuitive result to the fact that in their experimental design both buyers and sellers faced high penalties for not meeting must-serve load or not using must-run generation. While their results do show the impact of current limitations of supply and demand side flexibility on competition in the market, there is a danger that, as the authors admit, their results have little predictive power beyond the very specific conditions they study.

[77] Weiss did not consider the alternative of reducing seller concentration at those nodes where local market power was exhibited, as recommended by Brealey and Lapuerta (1997).

the strategic use of the uplift might have been predictable at the outset had the proposed mechanism been tested in the laboratory.

Discussion

Electricity market simulations and experiments tell us precisely what we would expect from any standard approach to assessing market power and competition, in any type of market. All of the studies described above report common results. First, large firms (i.e. with in excess of 40% of market capacity) are able to exercise market power in many periods, and the effect of this on both prices and welfare is significant. Second, 'small' firms act as price-takers even when allowed in the model to act strategically. Finally, a reduction in concentration in capacities (e. g. via divestitures) results in significant pro-competitive effects. There are also potentially significant pro-competitive effects from increasing the elasticity of demand, or increasing the production of low cost, 'must-run' generating stations.

The fact that these results were shared by both simple and more complex simulation models - i.e. those with and without a realistic representation of the transmission network - is significant. The only caveat is that when transmission constraints are included, this can result in firms enjoying periods of 'local market power', which may not be mitigated by an overall reduction in market concentration. This issue is discussed further in Section 4.2 below.

4 Specific Issues

Sections 2 and 3 have surveyed the growing theoretical and empirical literature on competition in wholesale electricity spot markets. As we have attempted to make clear, nothing in this literature provides sustenance for Ofgem's view that electricity markets are 'special', and hence require special regulatory rules. In light of the material presented above, we may now turn to a discussion of some of the specific issues raised by Ofgem in their submissions to the Commission.

4.1 Strategic Bidding and Price Manipulation in Spot and Forward Markets

One of Ofgem's key areas of concern is the ability of certain generators to increase wholesale electricity prices via the use of excessively high price bids in certain periods that cannot be justified on the basis of underlying costs. Ofgem points out that this has been a recurring theme since pool's inception:

> *"Since the introduction of the Pool in 1990, concerns about abnormal patterns of pricing, where price movements do not appear to reflect changes in demand and supply and underlying market conditions, have been a recurring issue.… Past evidence suggests that concern about the ability of certain generators to influence the price setting mechanism will remain. … Excessively high bids, with no movement in underlying costs, to exploit temporary market power was the focus of the most recent Ofgem investigation and of the investigation into Pool prices in winter 1997/98. In both of these cases National Power and PowerGen were found to have*

> *used their positions of market power to increase wholesale electricity prices by significant amounts, when other market conditions and costs remain unchanged."*

This issue is, of course, generic to all markets in which large or dominant firms have an ability to exercise market power. Most wholesale electricity markets around the world are subject to the abuse of market power by large firms, and the relevant empirical and simulation studies have now been described in some detail in the preceding section. Offer and Ofgem have also provided a good deal of evidence on this score over the past decade.

The important point for the purposes of this inquiry, however, is that the vast majority of evidence for strategic bidding to raise prices in the England and Wales pool relates exclusively to the price bidding strategies of dominant thermal generators (i.e. National Power and PowerGen), as Ofgem's own submissions make clear. The same is true in every other wholesale electricity market around the world. Ofgem's examples of strategic bidding by smaller firms to increase market prices are all instances of the manipulation of poorly designed and excessively complex market rules: for example, the 'price spikes' attributed to TXU and Brigg 'in 98/99. This was recognised by Offer (1999a) in their own analysis of the issue, and as a result Offer consulted on the desirability of changing the pool rules to simplify the bid format. These specific opportunities for market manipulation, to the degree that they still currently exist, should disappear entirely with the introduction of NETA.

Manipulation of forward contractual positions

In addition to the exercise of market power in the electricity spot market, Ofgem (2000c)(2000d) raise concerns over the manipulation of forward contractual positions -specifically by undercontracting in forward markets - to increase both contract prices and prices nearer to real time in the physical market. It is again notable that the examples Ofgem provides of this (alleged) form of abuse of market power all relate to the past market behaviour of the large thermal generators in the England and Wales market.

It is important to understand, however, that the exercise of market power in forward or contracting markets does not differ in kind from its exercise in the electricity spot market or pool. Large firms with market power will exercise it in whatever market yields the greatest returns at any given time.[78] This could conceivably consist of taking forward contractual positions to increase both contract prices and prices in the real time physical market. However what evidence exists on this subject suggests that forward markets have potentially significant procompetitive effects (see Section 2.3 above).

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[78] See Borenstein, Bushnell and Wolak (1999) for a discussion of the interactions between the multiple electricity markets in California. As these authors put it: "Participants will move between markets in order to take advantage of higher (for sellers) or lower (for buyers) prices. … The strong forces of financial arbitrage mean that any change in one market that effects the market price will spill over into the other markets."

Exceptions can of course arise when markets are poorly designed. Wilson (1999) and Cramton and Wilson (1998) point out that so-called 'single settlement systems' - in which all forward and spot markets are settled at 'real-time' market-clearing prices - magnify incentives to manipulate spot prices, since these determine profits on all prior transactions. They recommend clearing forward markets at their own prices to avoid this problem. Under the NETA proposals, the balancing mechanism 'cash out' prices are calculated as averages of accepted 'incs' and 'decs', giving rise to manipulability problems. As was demonstrated when the market was tested in laboratory experiments, these problems can be exacerbated by traders taking large forward market positions.[79] The solution, here as elsewhere, is to design market rules which avoid providing opportunities for such manipulations, or exacerbating incentives to exercise market power.

4.2 Transmission Constraints and Local Market Power

In their discussion of the ways in which firms have exercised market power in the England and Wales wholesale electricity market, Ofgem (2000c)(2000d) point to the role of transmission constraints in providing firms with an ability to exploit 'local market power.' Although Ofgem only mention this issue in passing, it is a problem which arises in most restructured and decentralised electricity markets. Indeed, it provides the clearest example of circumstances in which it is true to say that (in some sense) 'small' firms are able to exercise market power in electricity networks.

The regulatory and competition policy issues which arise when firms, protected from competition by transmission constraints, are able ask for high prices for their output, has received considerable attention in England and Wales (Offer 1992; Brealey and Lapuerta, 1997; von der Fehr and Harbord, 1998); Norway (Johnsen, Verma and Wolfram, 1999) and more recently California (Borenstein, Bushnell and Stoft, 1999; Bushnell and Wolak, 1999). In addition to these country studies a considerable theoretical and empirical literature exists on the subject (Cardell, Hitt and Hogan, 1997; Harvey and Hogan, 2000; Hogan, 1997; Joskow and Tirole, 2000; Nasser, 1997; and Weiss, 1998).

That transmission constraints in electricity networks can 'limit competition and create pockets of local market power', to paraphrase Harvey and Hogan (2000), is thus both widely recognised and well-understood. As demonstrated by Cardell, Hitt and Hogan (1997), when firms are protected by transmission constraints in particular zones or at some network nodes, this can effect their bidding incentives in other zones, or at other network nodes. Bushnell and Wolak (1999) have recently termed this 'the leveraging of local market power.'

The real issue however, in each of these analyses, is the ability of firms to charge high prices at network locations where they have local market power. Bushnell and Wolak (1999) put this well:

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79 London Economics (1999b) describe these manipulations; for a commentary see Harbord and McCoy (2000).

> *"Strategically located generators can profit from network constraints by raising their offer prices. The existence of transmission constraints means that these generator face less competition than those located elsewhere in the network. In the absence of substitutes for the output of these units, the market must either raise the locational price of energy (in the case of New Zealand), or make an above-market payment to the generator (in the case of England and Wales). Such generators are able to disproportionately influence prices, at least in their local areas. During the early years of operation of the E&W pool, for instance, strategically located generators learned to adjust their bids to take advantage of their constrained-on status, causing a year to year increase of constrained-on payments of over £70 million. Supply bids from these units appear to have been limited primarily by a fear of regulatory intervention."*

That generating units protected by transmission constraints have manipulated prices to earn excessive profits in England and Wales is probably beyond dispute. Offer (1992) threatened the two largest generators with price controls if other means of alleviating the problem could not be found. That Offer took the problem seriously is evidenced by the statement that, *"the present system [of constrained-on payments] permits generators located behind transmission constraints to name their own price."*[80] As noted by Bushnell and Wolak (1999), the problem has now largely been alleviated, no doubt in part due to the threat of regulatory intervention, but also from a strengthening of the transmission network which has reduced reliance on particular generators for network support, and incentives given the NGC to undertake investments to alleviate constraints.

In California a different approach to this issue has been taken. There, so-called 'must run' stations have had price-controlled RMR contracts imposed upon them, which allow the system operator to call on these stations at fixed prices. According to Bushnell and Wolak (1997) however, these contracts have been so poorly designed that they are themselves subject to manipulation by generators.[81]

While transmission limits and constraints may give rise to local market power, the regulatory approach to this does not require heavy-handed solutions. The standard approach to market definition taken by both regulators and competition authorities alike, is more than adequate for dealing with this issue. Under this approach a market is defined '*as a product or group of products such that a hypothetical profit-maximizing firm that was the only present or future producer or seller of those products would impose at least a small but significant and nontransitory increase in price (SSNIP), assuming the terms of sale of all other products are held constant. A relevant market is a group of products and a geographic area no bigger than is necessary to satisfy this test*.' Literally by

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80 However, notably, the Director General at that time was concerned that "more competitive solutions be sought before price controls are considered."

81 See also Joskow (2000) for a discussion for these contracts. Bushnell and Wolak point out that the prices paid for energy from 'must run' plant under the contracts is so high as to distort bidding incentives in the energy markets.

definition, firms exercising 'local market power' in an electricity transmission network would be considered to be monopolists, or dominant firms, according to this test. The solution is therefore to apply the competition policy framework which already exists in Britain and in Europe, something which the UK electricity regulator has been slow to do.[82]

4.3 Capacity Withholding and Capacity Payments

Another area of concern discussed in Ofgem's submissions is the manipulation of the capacity payment mechanism. The price-setting mechanism in the England and Wales pool is unique in that it includes a 'capacity element' intended to compensate generators for making capacity available to the system, particularly in times of peak demand. The justification for doing so comes from the peak-load pricing literature. Although demand and supply conditions may vary continuously over the day, pool prices are determined in advance for discrete (i.e. half-hourly) periods. This means that in any period there is some non-zero probability that supply will be insufficient to meet demand and rationing or 'loss of load' may occur.[83] This probability is denoted by LOLP. The pool determines Pool Purchase Price (PPP) - the price paid for 'in merit' or scheduled generation - for each half hour by the formula:

$$PPP = SMP + LOLP \times (VLL - SMP)$$

where SMP = system marginal price, VLL = the value of lost load,[84] and LOLP×(VLL-SMP) is often referred to as the 'capacity element'.

Manipulation of capacity bids to increase the value of the capacity element has been a feature of the England and Wales pool since its inception. Wolak and Patrick (1997) examined the issue of capacity withholding in the England and Wales pool during the first five years of its operation. They argued that capacity bids are a potentially more 'high-powered' instrument than price bids for manipulating pool prices, because:

- price bids are fixed for 48 hours, while capacity bids can be changed practically continuously;
- capacity availability is more difficult to monitor than price bids versus costs, and hence less subject to regulatory scrutiny; and

82 It is notable that in California the market authorities evidently had little difficulty in identifying 'must run' stations, and regulating them. (Which stations these are varies over time, a feature which Ofgem appears to find particularly troublesome). Although the regulatory solution adopted has evidently fallen somewhere short of perfect, this would not appear to be due to a lack of regulatory powers, nor an inability to regulate the market behaviour of 'small' firms.

83 In electricity parlance "load" = "demand", and hence loss of load refers to the event that a consumer or consumers may be temporarily prevented from consuming.

84 The value of lost load is intended to reflect the consumer welfare loss from being denied supply, and hence the value of an additional unit of capacity in the event of rationing (i.e. consumers' marginal or average willingness to pay for electricity).

- the LOLP function is non-linear and extremely convex at low reserve margins, allowing for large effects on the capacity payment from relatively small changes in capacity bids.

Wolak and Patrick (1997) analysed half-hourly market-clearing prices and quantities, and half-hourly bids and availability declarations from 1991 to 1995, and cited several pieces of evidence that National Power and PowerGen were strategically withholding capacity. They found that the percent of total capacity declared unavailable by National Power and PowerGen in 1995 during off-peak months was more than twice the average amount of capacity declared unavailable by all generators in the same period. In addition, they calculated average availability factors by fuel type for National Power and PowerGen and compared them to industry benchmarks based on data for comparable units. For every fuel type, the availability factors for both National Power and PowerGen were below the industry benchmark. The authors concluded:

> *"The market rules governing the operation of the England and Wales electricity market, in combination with the structure of this market, presents the two major generators—National Power and PowerGen—with opportunities to earn revenues substantially in excess of their costs of production for short periods of time. … Because of the rules governing the price determination process in this market, by the strategic use of capacity availability declarations these two generators are able to obtain prices for their output substantially in excess of their marginal costs of generation. … The evidence presented makes it hard to believe that PowerGen and National Power do not strategically set their supply functions and available capacity to obtain prices that are temporarily significantly above average production costs"*

Wolak and Patrick are not alone in arguing that the capacity payment mechanism has been manipulated in the England and Wales pool by the two largest generating companies. As Newbery (2000) points out:

> *"Capacity payments are extremely nonlinear in the margin between capacity declared available and peak demand. If this margin falls from 20% of capacity to 10%, then the capacity payments increase from negligible levels (a few pence per MWh) to more than £20/MWh. … The method of computing the loss of load probability greatly overstates the actual probability of a loss of load, and hence provides overgenerous capacity payments."*

Evidence that capacity withholding has periodically been used to manipulate capacity payments in the England and Wales is thus extensive, and rarely disputed. Indeed, this experience has ensured that no other region or country in the world has imitated this aspect of the England and Wales electricity market, and is probably the most widely cited design flaw in the market.[85]

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[85] See Wilson (1999).

Ofgem itself recognises that the capacity payment mechanism is flawed and hence subject to abuse. Ofgem (2000c) noted that:

- the complex mathematical rules used to determine capacity payments mean that pool prices can be significantly influenced by capacity availability strategies;
- when the demand/capacity balance is relatively tight, the payments made to generators to make capacity available are highly sensitive to small changes in capacity availability; and
- the problem is exacerbated under the Pool rules because of the different assumptions used to measure the availability of older generating plant when calculating capacity payments.[86]

The capacity payment mechanism in the England and Wales pool is a classic example of 'market design by engineers', which failed to take into account of the effects of market competition or market power in designing the pool pricing formula. Other countries have now learned from this experience and declined to make the same mistake in their own market designs. Indeed, as pointed out in von der Fehr and Harbord (1998), the designers of the England and Wales pool simply implemented an approximation to a standard 'peak-load pricing' formula, with little thought given to the consequences this might have in an imperfectly competitive electricity wholesale market.[87] While this may have been a natural mistake to make in 1989 when the pool was originally designed, its consequences have now been understood for more than half a decade. The solution has clearly always been to abolish the capacity payment mechanism, an outcome which has now finally be achieved.[88]

4.4 Market Complexity and Market Manipulation

"One of the lessons that I have learned in the course of creating new electricity market and transmission institutions is that the microstructure of the market rules that govern energy and ancillary services markets and the management of congestion are at least as important for determining market performance as are traditional structural and behavioural considerations. Here the devil is truly in the details." (Paul Joskow, "Deregulation and Regulatory Reform in the US Electric Power Sector." MIT.)

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86 'Plant that was commissioned before 1992 is artificially assumed to be more reliable than plant commissioned since 1992. As a result, capacity payments are derived from a formula with a number of unrealistic assumptions that result in payments that are highly sensitive to the withdrawal of particular generating plant.'

87 See also von der Fehr and Harbord (1995).

88 Newbery (2000) may be the only dissenting voice. He believes – controversially (see Section 2.3 above) – that pool prices are set by the conditions of entry, and hence that the effects of capacity payments on pool prices have been exaggerated.

4.4.1 Are electricity markets 'complex'?

Ofgem make frequent reference in their submissions to the complexity of wholesale electricity markets and their market rules. Ofgem view this complexity as inherent to electricity markets themselves, creating unavoidable opportunities for market manipulation and abuse:

> *"The requirements for minute by minute balancing of electricity systems give rise to the need for complex rules and to the resulting opportunities for gaming that such rules create. … The existing Pool Rules are highly complex and the Pool rule modification process is slow and cumbersome. … However, while rule changes that prove necessary in the light of experience of operating under the NETA will be simpler and quicker, changes to the market rules do not alter the fundamentals of the economic conditions that exist in electric systems close to real time. Past evidence indicates that, as a result, when one rule loophole through which market power can be exploited is closed, market participants can readily find other ways in which similar effects can be achieved, not least because of the complexity of the rules. The Pool Rules are particularly complicated but the complexity in part reflects the complexity of the underlying physics and economics of electric systems."*

But are electricity markets particularly complex? In a study of generator bidding strategies in the Australian National Electricity Market, Frank Wolak (1999) observes that: *"A competitive electricity market is an extremely complicated non-cooperative game with a very high-dimensional strategy space."*[89] Is the complexity Wolak refers to a unique feature of electricity auctions, or merely a feature of some existing electricity market designs? In our view, it is clearly the latter. What complexity does inarguably exist in the generation and transmission of electricity, need not, and should not, be incorporated into the market rules or the market design.

The England and Wales pool, as Ofgem admits, is fiendishly complex. This is particularly true of its bid format. That this has permitted manipulation of the market rules is uncontroversial. That complexity of this type is somehow an inherent feature of trade in electricity however, is not a widely accepted view. To cite Chao and Wilson (1999):

> *"There are two basic bid formats for energy. In the classic England-Wales version a supplier provides a "multi-part" bid for each unit that includes – besides capacity availability (such as lower and upper operating limits) and operating and ramping constraints – startup costs, no-load costs, and a piecewise-linear schedule of marginal operating costs. This plethora of data (reportedly 51 numbers for each unit in the England-Wales system) is used in the optimization to decide which units to commit, the hours in which they operate, and their time-profile of operating rates. Newer*

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[89] Wolak (1999) reports on a simulation analysis carried out as part of a larger study undertaken for Macquarie Generation Pty by the current authors. We have not discussed this analysis here as it is not directly relevant to the issues of concern in this report.

> *versions such as New England omit startup and no-load costs, taking the view that suppliers can internalize these costs in their bids.*
>
> *Other exchanges such as California and NordPool operate on the principles of self-scheduling and market clearing. A supply bid is simply an offer to supply energy at any price at or above the bid price, and similarly a demand bid is an offer to take energy at any price at or below the bid price. No system optimization is involved, and it is each supplier's responsibility to schedule its own plants optimally to provide the energy sold."*

Good market designs in electricity, as in any other type of market, minimise complexity via the use of simple rules which transparently translate the information provided by market participants (e.g. simple price and quantity bids), into market prices and allocations. The basic principle was explained by Binmore and Harbord (1997):

> *"An optimal mechanism design decentralises - so far as is practicable - decision-making to the level where the necessary knowledge and experience resides. In the case of the electricity pool, this means that engineering decisions about supply and capacity availability should not be determined within the pool. The electricity pool should provide engineers with the information and the economic incentives they need to make efficient decisions, but it should not seek to tie their hands by artificially constraining their choices further."*

Neither the current electricity pool in England and Wales, nor the proposed New Electricity Trading Arrangements, adhere to this principle of good market design. Indeed, Ofgem(2000d) is already worrying about the complexity of market rules on which the ink has barely had time to dry!

> *"The rules governing [the Balancing Mechanism] are inevitably complex because they have to deal with balancing the system over very short timescales. Participants will submit "bid/offer pairs" specifying the price at which they are prepared to move away from their declared position (their final physical notification or "FPN") and also the price for undoing any action that the SO instructs. For example, a generator can say that it will increase its output from 100 MW to 120 MW for 10 £/MWh but will only pay back 8 £/MWh for reducing its output back down from 120 MW to 100 MW. Up to 10 bid/offer pairs (5 above the FPN and 5 below) can be submitted for each generating unit for each half-hour."*

Unfortunately, Ofgem's description of the new balancing mechanism is merely the tip of the iceberg. The price-setting mechanism being proposed for this market has now become so complex that few market participants can any longer claim to properly understand it.[90]

There is nothing inherent in electricity as a commodity that makes the design of electricity auctions particularly difficult or complex relative to other types of

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90 See the reports produced by the NETA programme, DISG 29/01 and the Balancing Mechanism Specification Document (version 1.1.).

markets. The recent FCC radiospectrum auctions in the United States provide a case in point. The 'good' for sale in these auctions was infinitely more complicated then the mere injection or withdrawal of energy from an electricity network.[91] And the auction design needed to accommodate not only the fact that bidders faced real informational problems (e.g. the 'Winners' Curse'), which are not present in electricity markets, but also the desire of bidders to build up efficient aggregations of complementary licenses.[92] Cramton (1995) describes the simultaneous multiple-round auction format:

> *"A simultaneous multiple-round auction is similar to a traditional ascending-bid "English" auction, except that, rather than selling each license in sequence, a large set of related licenses is auctioned simultaneously. In every round, a bidder can bid on any of the licenses being offered. The auction does not close until bidding has ceased on all licenses that is, until a round goes by in which there are no new bids on any of the licenses. There are three critical features of this method. First, the ascending-bid aspect allows the bidders to react to information revealed in prior rounds. This reduces the winner's curse, enabling the bidders to bid more aggressively. Second, by auctioning a large set of related licenses simultaneously, bidders are able to condition on relative prices across licenses. Since bidder valuations depend on the combination of licenses held, providing this price information on related licenses is essential to the formation of efficient aggregations of licenses. Some licenses are complements, whereas others are substitutes. The simultaneous sale of related licenses in an ascending-bid auction gives the bidders the flexibility they need to express these value interdependencies. In addition, it assures that similar licenses will sell for similar prices. Third, keeping the bidding on all licenses open until there are no new bids gives the bidders the most flexibility in switching among license aggregations as prices change."*

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91 To quote one of the auction's designers, Peter Cramton (1995): "The licenses come in three different types:50/50 kHz paired licenses, 50/12.5 kHz paired licenses, and 50 kHz unpaired licenses. With the "paired" licenses, the first number denotes the amount of outbound capacity (from transmitter to consumer unit), and the second number denotes the amount of inbound capacity (from consumer unit to transmitter). An unpaired license consists of only outbound capacity. Inbound spectrum is not the same as outbound spectrum. The inbound spectrum, which is in a very quiet (low interference) part of the spectrum (900 MHz), can only be used for low-power transmissions. This makes it ideal for transmission from small consumer devices but ill-suited for transmission from network transmitters, which must use greater power to reach the low-power consumer devices. Hence, one 50/50 kHz paired license is not the same as two 50 kHz unpaired licenses. There are five 50/50 kHz licenses (lot numbers 1 to 5), three 50/12.5 kHz licenses (lot numbers 6 to 8), and three 50 kHz licenses (lot numbers 9 to 11). License 9, one of the 50 kHz licenses, was not up for auction because it had been set aside for Mtel as a Pioneer's Preference award."

92 The Winner's Curse refers to the problem faced by a bidder in an auction who, having an overly optimistic estimate of the value of the object being sold, outbids all other rivals. The very fact of winning should tell the bidder that all of the other bidders placed a lower value on the object, and hence that he has overbid.

Despite the evident complexity, the radiospectrum auctions in the United States have been a notable success, arguably only outdone by similar auctions recently held in Britain. The principle followed by the auction designers was to allow bidders the flexibility they required to express their preferences, while avoiding opportunities for complex manipulations of detailed auction rules.[93] By comparison, an auction for a homogeneous commodity such as electricity poses a much simpler problem, at least once it is understood that the engineering complexity involved in its generation is best left to be internalised by power company engineers, and not to be included in the bid format or auction design.

4.4.2 Market manipulation versus the abuse of market power

Broadly speaking, firms exercise market power when they withhold capacity or increase their price offers in a market in order to influence market prices, and increase their profits.[94] In contrast, firms behave competitively when they 'truthfully' reveal in their price offers or capacity bids their actual willingness to supply output in the market, e.g. by making available all of their capacity at its avoidable, or marginal, cost. Different types of market organisations, or market 'designs', give rise to different types of strategic opportunities for exercising market power, so an understanding of how market power will be exercised in any particular market requires an understanding of the strategies available to firms, and an equilibrium analysis of the market game being played.

A market mechanism which does not induce firms to behave competitively, or to 'truthfully' reveal their information, is often called 'manipulable' in the economics literature, but this is not the sense in which this term is used when discussing the opportunities for market manipulation which arise from complex and imperfect auction designs in electricity and other markets. Poorly designed market rules can create opportunities for market manipulation and the exercise of market power that would not otherwise exist. One clear example is the capacity payment mechanism in the England and Wales pool, discussed above. In this case, engineering detail in the price-setting formula has provided firms with a mechanism for exploiting even modest amounts of market power in a way that could not arise in markets which evolve in the private sector. Another example is the manipulation of the balancing mechanism prototype which occurred in the market experiments carried out for the NETA programme. In both of these cases market rules invented by market designers and engineers create opportunities for

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93 The original FCC auction design failed in this in one arcane detail which turned out to be surprisingly important. The early auctions allowed bids to be specified down to the penny, and this gave bidders the opportunity to use the redundant digits in their bids to communicate with each other, and hence collude (see Cramton and Schwartz, 1999: "Market numbers are two or three digits and bids are typically six figures or more, so a bid could contain at negligible cost the market number as its last few digits, prefaced by leading zeroes to make the trailing digits stand out.") This design flaw certainly demonstrated, as Joskow (2000) notes, that the devil is often found in the details in market design, and the mistake has been rectified in subsequent spectrum auctions.

94 See Section 5 below for a more detailed discussion, and some caveats to this characterisation.

firms to 'fiddle' the system which involve something more than (and different from) the traditional exercise of market power by large firms.

Although easily seen in examples, the general distinction between the exercise of market power and the manipulation of market rules is not always easy to maintain. It is typically large firms with substantial market power which benefit most from manipulating arcane market rules, although there can be exceptions to this. Firms with market power will exploit whatever profitable opportunities for its exercise they are provided with. Good market designs minimise such opportunities for manipulation (or 'gaming') of the market.

In extreme cases, badly designed market rules can even create opportunities for market abuse by 'small' firms, that clearly should not exist. The England and Wales pool has been particularly, and perhaps uniquely, prone to this problem. Ofgem's examples of a market manipulation by modestly sized firms are all of this type. All are made possible by a complex price determination algorithm which even the regulator has frequently had difficulty in understanding!

Ofgem is absolutely correct, however, to point to the market power problems that have arisen in the England and Wales pool as a result of the 'plethora of information' that generators currently supply to the market. These problems have been much-analysed, and consequently well-understood, for many years. The answer is to return to the basic principles of good market design, and to eliminate any market rules which provide opportunities for manipulation. Ofgem's view that electricity markets are by their very nature unusually complex, and hence that complex and manipulable market rules are unavoidable, is not accepted by economists or auction theorists who have become increasingly involved in designing markets for electricity. Nor does complexity by itself necessarily lead to increased potential for the abuse of market power, as the successful design of radiospectrum auctions has clearly demonstrated.

Under the New Electricity Trading Arrangements to be introduced in the autumn, the particular forms of market manipulation which have plagued the England and Wales electricity market for the past decade, should finally disappear. This does not mean that all market power problems will have been resolved. However the market structure in generation has progressively become so unconcentrated that the potential for a truly competitive market to emerge is now within reach. The task of Ofgem should be to ensure that the new market rules do not simply repeat the mistakes of the past, and create a host of new market abuse problems to replace those that have recently been abolished.

5 Defining and Diagnosing Market Power in Electricity Markets

In order to understand - and regulate - the exercise of market power, it is first necessary to characterise competitive behaviour in electricity (and other) markets. Electricity markets do not differ fundamentally from any other market in this respect. We can do no better than quote Borenstein, Bushnell and Wolak (1999) for a concise statement of the standard approach to this topic:

> *"In a competitive market, a firm is unable to take any action, including output decisions or offer prices, that will significantly affect the price in a market. In a competitive market, a firm is always willing to sell a unit of output so long as its cost of selling that unit is less than the price it receives for that unit. Its offer price will always be its marginal cost….*
>
> *In contrast to price-taking firms, a firm with market power can unilaterally influence the market price by withholding output at the margin or raising the price at which it is willing to sell this marginal output. A firm exercises market power when it reduces its output or raises the minimum price at which it is willing to sell output in order to change market prices."*

Firms in perfectly competitive markets are inexorably driven by competitive forces to offer prices near to their avoidable or marginal costs. Conversely, firms with market power have an ability to behave strategically to increase market prices, and their own profits. Precisely how firms compete and market power is exercised, however, depends upon the exact structure of the market, and in particular its price-setting mechanism. Understanding this is crucial for diagnosing market power in any particular context.

In the equilibrium of a textbook 'Cournot' game, for instance, firms compete by offering quantities of output to the market, and prices are exogenously set by an 'auctioneer' to match demand and supply.[95] Firms exercise market power by reducing the quantities offered to the market, resulting in higher market-clearing prices and profits. In a textbook 'Bertrand' game, on the other hand, firms receive their own price offers on each unit of output sold (i.e. precisely as in a discriminatory auction), and market power is exercised by firms offering prices in excess of marginal cost, and consequently selling less than the competitive output.

Apart from the 'balancing mechanism' envisaged in the NETA arrangements however, which uniquely is organised as a (Bertrand-like) discriminatory auction, no decentralised electricity market organised to date corresponds to either of these standard textbook formulations. Understanding this is crucial both for the analysis of competition and the identification or diagnosis of market power. All decentralised electricity wholesale markets which exist currently are organised as uniform, first-price auctions in which generators submit price-quantity bids, and every unit is sold at the same market-clearing price, or SMP. The appropriate equilibrium concept is therefore neither Cournot or Bertrand, but the Nash equilibrium for the first-price, multi-unit auction. As we have discussed in Section 2.1 above, this can involve:[96]

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95 Tirole (1988) is the best reference for a discussion of standard models of oligopoly competition.

96 For other analyses based on the multi-unit auction model see García-Díaz and Marín (2000) and Stachetti (1999).

(i) all firms bidding competitively at marginal cost in low demand periods;

(ii) all firms but one bidding in all of their capacity at marginal cost, while one firm bids a high price and sells a quantity less than its available capacity, or;

(iii) all firms employing mixed, or randomised, pricing strategies, with price offers bounded below by marginal cost and above by the highest feasible price.

The crucial implication of the equilibrium analysis of electricity auctions is that the identification of firms exercising market power cannot simply be equated with identifying those firms asking for, or setting, 'high' prices at the margin. Under both (ii) and (iii) above the firm or firms which most successfully exercise their market power are those which bid low prices in the (pure or mixed strategy) Nash equilibrium, and consequently 'free-ride' on the high prices set by other firms. Further, under (i) all firms are bidding competitively, and which firm sets the system marginal, or market, price, depends on where demand intersects the competitive industry supply curve in any particular period. It is entirely possible that the firms whose bids frequently determine the market price are small and competitive with no ability to influence market prices. Borenstein, Bushnell and Wolak (1999) make essentially the same point in their study of market power in the California electricity market:

> *"Even in a market in which some firms exercise considerable market power, the marginal unit that is operating could have a marginal cost that is equal to the price. When a firm with market power reduces output from its plants, or equivalently, raises its offer price for its output, its production is usually replaced by other, more expensive generation that may be owned by non-strategic firms. Thus, although the marginal cost of the most expensive unit operating at a given time may indeed equal the market clearing price, market power would be still present if there were other generators with costs below that price that are choosing not to supply power."*

These considerations lead to some important conclusions for the identification and diagnosis of market power in electricity markets. The most important of these is that simply identifying firms which are at the margin, i.e. set market prices, for significant periods of time, would appear to have little or nothing to do with the identification of which firms possess market power. Hence Ofgem's criterion for identifying firms with market power, i.e. *"companies which account for at least 5% of system marginal price setting"* appears to be flawed, and to lack a solid foundation in equilibrium analysis.[97]

It is difficult to overemphasise this crucial fact, which only an analysis of equilibrium bidding strategies can reveal. Simply observing that a particular firm is setting system marginal price over a number of periods tells us nothing about the

[97] Under the balancing mechanism in NETA, of course, Ofgem's criteria will have no validity or relevance, since there will no longer be a system marginal price to be determined.

potential ability of that firm to exercise market power, especially in the absence of information allowing us to compare the prices bid to the firm's marginal costs. Indeed we would expect to observe both small and large firms setting system marginal price, with competitive price bids, in periods in which demand is relatively low and hence market conditions competitive. Conversely, observing firms which bid in most or all of their capacity at low prices does not necessarily indicate an absence of potential to exercise market power.

This naturally poses the question as to how the identification of firms with market power in electricity auctions should be undertaken. We consider a number of options below.

5.1 Bid Prices Versus Marginal Cost Comparisons

A standard approach to addressing this question was first taken in von der Fehr and Harbord (1993) who analysed bid and marginal cost data for the two large thermal generating companies in the England and Wales pool. This approach has subsequently been followed by other researchers such as Wolak and Patrick (1997), Wolfram (1998)(1999a) and Borenstein, Bushnell and Wolak (1999). These studies have been described in Section 3.1 above.

Comparisons of firms' bids against marginal cost data can tell us a great deal about the exercise of market power in electricity markets. This is because, as noted above, competitive, or price-taking, firms bid at marginal cost. We can therefore be sure that a firm which is frequently bidding in prices well in excess of its marginal cost (it may or mat not be setting system marginal price), is exercising market power. Therefore these studies give some indication of the extent to which market power has been exercised over the periods considered. They may also provide an indication of *which* firms have been exercising market power. They do not, however, provide a complete answer to the question as to which firms are, or are potentially capable of, exercising market power, for the reasons specified immediately above.

5.2 Residual Demand Analysis and Market Power

A more thorough approach to answering this question would be to employ some version of the residual demand analysis (see Baker and Bresnahan, 1992). The 'residual' demand curve measures the responsiveness of its sales to changes in its price, taking into account the demand responses of buyers and the supply responses of its competitors. In a traditional residual demand analysis, a firm's market power is measured by the degree to which it is able to increase price without losing sales, or more precisely the degree to which it is able to profitably raise its own price above competitive levels.

This approach has the merit of corresponding particularly closely to the equilibrium analysis of electricity auctions described in Section 2.1 above, and the same applies to discriminatory, or 'pay-your-bid' auctions.[98] In either auction

98 See Armstrong, Cowan and Vickers (1994), Fabra (1999) and Fabra, Harbord and von der Fehr (20000).

format, in equilibrium a firm can only exercise market power when it is not forced to compete fiercely to sell each unit of output. Another way of saying this is that, after accounting for the capacity of all other firms, in at least some periods a particular firm's capacity is required to match supply with demand, and hence the firm faces some positive amount of residual demand (i.e. total demand net of the available capacities of all other firms).[99] When no firms' capacity is required to satisfy market demand, the unique equilibrium bidding behaviour is 'Bertrand-like', and all firms bid at marginal cost. Further, any firm whose capacity is not required to meet demand in any given period has a unique equilibrium strategy to bid in its capacity at marginal cost, irrespective of the strategies followed by other firms. Hence only when a firm faces a positive residual demand does it possess any incentive to reduce output in order to increase market prices.

A useful approach to addressing the question of which firms have the potential to exercise market power then is to ask which firms face positive residual demand in any given period or for any given level of demand. Since in electricity markets demand varies significantly half hour by half hour, the answer will be different depending upon which half hour, or demand level, is chosen. There will undoubtedly be a small number of periods of extremely high demand in which most firms have some degree of market power. However for firms which do not account for a large or significant proportion of total industry capacity, the number of such periods will be correspondingly small. By asking which firms face residual demand over periods such as a month, a year or a decade we could obtain quite accurate estimates of the extent to which any particular firm was able to exert market power, for sustained periods of time.

However even without undertaking such an exercise, we can see immediately that the implication of this approach is that a firm's market power is strongly correlated to its size. Small firms will encounter few occasions when they have any ability to significantly influence market prices, while for large firms such occasions will be much more numerous. It is this fact which is explained in Proposition 5 of von der Fehr and Harbord (1993) (see Section 2.1 above). They addressed the question of how an increase in the number of independent generators would effect (average) prices in the England and Wales pool. In particular they analysed what would happen if the existing generators were split up into smaller units, so that a given total capacity was divided between a larger number of independent firms. Not surprisingly, given the above intuition, they found a strong pro-competitive effect, i.e. prices were lower in the less concentrated industry. The intuition for this was explained by von der Fehr and Harbord (1993) as follows:

> *"The probability of any generator setting system marginal price [in the mixed strategy equilibrium] decreases as the number of generators*

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99 An important caveat is that this is only necessarily true when each firm's costs and capacities are 'common knowledge', i.e. known by all firms in the market. This is generally held to be a good assumption in restructured electricity markets. See for example, Krishna and Tranaes (1999). When traders have imperfect information concerning each others' costs, the equilibrium analysis is more complex (see Ausubel and Cramton, 1997).

> *increases. Hence the incentive to bid high in order to raise market price decreases. The overall effect is to reduce the probability of any generator submitting a high bid, and hence of a high system marginal price. … It therefore seems reasonable to conclude that for a given number of generating sets in the industry, the system marginal price will be a decreasing function of the number of owners, or generators controlling the sets, i.e. the industry concentration ratio."*

An analysis of the residual demand facing any firm would provide the best evidence of whether or not the firm was in a position to exercise market power for significant periods of time.[100] Ofgem have evidently not undertaken such a study –although all of the necessary data is easily available – and their approach to identifying firms with market power in the England and Wales electricity market lacks both intellectual rigour and economic coherence.

5.3 Concentration Measures

Concentration measures, such as firms' market shares, or more sophisticated versions such the Hirschmann-Herfindahl Index (HHI), are traditionally employed in competition policy and regulatory inquires to gauge the degree to which individual firms, acting independently or in a coordinated fashion, may be able to exercise market power. These crude measures, which take no account of important factors such as demand elasticities, the nature of competitive interaction in the market, nor the ease of entry, are just that, i.e. crude, and not to be much relied upon in a thorough investigation.

Indeed, it is widely recognised that to the extent that a market share has a role to play it is as a negative test: firms which are small in the relevant market are unlikely to have much influence over market outcomes, and hence when a market is highly unconcentrated there is likely to be little justification for interference by a regulatory or competition authority. This is the way in which concentration measures are used by most competition authorities, and this role as a 'negative test' is perhaps made most explicit by the widely-cited US Department of Justice Horizontal Merger Guidelines.

In the preceding sections of this report we have argued that electricity wholesale markets do not differ fundamentally from any other market in that the incentives to bid strategically in order to influence market prices and achieve more profitable market outcomes, are less for small firms than they are for large firms. In other words, market outcomes tend to become more competitive as industry structure becomes less concentrated. Hence market concentration measures or indices are as capable of playing their traditional - if highly imperfect - role in this context as in

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100 Such an analysis would be slightly more complicated than described above because of the different characteristics of the generating plants owned by different companies. So it would need to take into account the flexibility or inflexibility of different types of plants. A firm's incentives to exploit market power in the periods in which it faces some residual demand, by reducing output for instance, could well be tempered by a need to keep plant running over longer time periods. Such considerations are of course standard to the analysis of competition in electricity markets.

any other. That this is the case has been demonstrated by the various theoretical analyses discussed above, electricity market simulation studies, and empirical evidence on bidding behaviour and prices in existing deregulated electricity wholesale markets. (This literature has also been nicely summarised by Weiss, 1998).

The analysis of electricity markets is further complicated, however, by the difficulty of determining the size of the relevant market. Depending on supply and demand conditions, as well as on the state of the transmission system, the ability to supply power from one geographic area to another may be severely limited at certain times and less so at others. So that the size of the market depends on the degree of congestion of the transmission system, which in turn may depend upon the actions taken by all firms in the market.

Several models, which incorporate these complexities into the study of oligopolistic behaviour in electricity markets have been proposed, and these have been discussed in earlier sections of this report (Cardell, Hitt, and Hogan, 1998; Nasser, 1997). These studies emphasise the importance of local market power, and hence of applying appropriate market definitions.

A recent paper by Borenstein, Bushnell and Knittel (1999) however, purports to take a different view:

> *"Although industry concentration and individual firm market share are often correlated with market power, this is not always the case. There are many factors beyond the number and size of firms in a market that impact the degree of competition within an industry…These factors are not captured by measures of the concentration of an industry. Concentration measures indicate the current distribution of sales or capacity, but cannot tell you what will happen to prices when one firm reduces its output. This is a critical question in the electricity industry where the product is, with some exceptions, not storable and short-run demand is relatively inelastic. Because of these factors, concentration measures can often be an inappropriate 'screen.' Even though one firm may have a relatively small market share at a given demand level, it may be the case that if that firm reduced output, no other firm would be able to replace that supply because of cost, capacity or transmission constraints."*

Although Borenstein, Bushnell and Knittel seem to be presenting an argument for the inapplicability of concentration measures to decentralised electricity wholesale markets, all of these considerations will apply to practically any market which comes under the purview of regulators or competition authorities. Concentration measures *"…cannot tell you what will happen to prices when one firm reduces its output"*, in any industry, regulated or otherwise, nor can they tell you how firms are likely to respond to a given competitive environment, nor how consumers will react to price changes. None of these considerations differentiates electricity wholesale markets from any other market.

Where Borenstein, Bushnell and Knittel make more cogent points these relate to:

- inelastic demand implying that in certain circumstances even small firms may have an incentive to increase prices or withhold capacity
- transmission constraints creating pockets of local market power

We have discussed these issues already, and at some length, in the preceding section. The point of a residual demand analysis is precisely to tell us which firms are potentially able to exercise power in any given period, or for a given level of demand. Small firms are less likely to be in this position, and the likelihood decreases in the size of the firm's capacity.[101]

Transmission constraints, as we have noted, imply that separate markets may be created, as recognised explicitly in systems with zonal or nodal pricing regimes. Here concentration measures do their job so long as the relevant markets are defined correctly. Concentration measures are of course meaningless when the 'market' considered is defined either too broadly or too narrowly.

6 Do Electricity Markets Require Special Regulatory Rules?

That the England and Wales electricity pool has been subject to the abuse of market power by the dominant thermal generators practically since its inception is so widely known, and so well studied, that it hardly requires further elaboration or comment. Both the economic theory of competition in electricity wholesale markets, and the empirical evidence, provide overwhelming confirmation of this fact. The England and Wales market has also been subject to manipulations of its complex and elaborate price-determination rules, not always by firms which were unambiguously dominant in their respective markets. However economists have always understood that it is possible to design market rules which are so flawed either in their conception or their operation, that even small firms will have little difficulty in devising means of manipulating them to their advantage.[102]

Since the England and Wales electricity market was amongst the first to be restructured, or 'deregulated', it is perhaps not surprising that it has been particularly subject to problems of market power and market manipulation. Regulatory authorities and economists working on electricity market reform in other parts of the world have observed this experience, and been the beneficiaries of it. Amongst economists working in this in this area however, it is a widely-held view that the UK regulatory authorities have been too slow to learn

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101 The type of simulation analysis which Borenstein, Bushnell and Knittel propose to put in the place of reliance on concentration measures would be advisable in any regulatory or competition policy inquiry in any industry. And despite what has been said in the above citation, the authors recommend ignoring the impact of small firms in their analysis, for all of the usual reasons, *vis*: "*For a small firm, price-taking output choices differ very little from Cournot output choices*", hence, "*we model only the larger firms as Cournot competitors*."

102 For recent and unambiguous evidence of this see London Economics (1999b), which is discussed in Harbord and McCoy (2000).

from their own experience of dealing with these problems, or to grasp their underlying causes. Subsequent efforts to reform the trading arrangements, or to regulate market behaviour, have consequently been misdirected or misconceived. Borenstein and Bushnell (2000) are particularly clear on this point:

> *"England provides perhaps the most serious cautionary tale about electricity restructuring. A high level of dissatisfaction with the outcomes in the British power market has led to near total demolition of those market institutions. Much of the blame that has been placed on the market's design should more properly be attributed to the market structure. The British experience with electricity markets over the past decade has so seriously eroded faith in markets that ominous "good behaviour" clauses have been proposed as a requirement for generation firm licensing there. These clauses have the potential to be far more arbitrary and intrusive than the traditional forms of regulation that have been employed in the U.S. during the twentieth century."*

And Harvard economist Catherine Wolfram (1999b) argues essentially the same point at greater length:

> *"It is clear that prices for wholesale power in the UK have been above competitive levels. From 1992-1994, prices were on average 25% above the costs of the last plant needed to generate electricity in a given period, suggesting that if prices were being set competitively, they would be substantially lower. Since 1994, fuel costs, which are the main input cost for electricity-generating plants, have come down though prices have not fallen accordingly. This suggests margins are now higher and provides further evidence that prices are not responding to competitive forces.*
>
> *The regulatory body overseeing the electricity industry has taken several steps to address the high price levels. The regulator has issued a number of reports on pool prices (at last count, ten since 1990), he instituted a cap on pool prices in 1994-1996, and, most substantively, he required the dominant generators, National Power and PowerGen, to divest of some of their generating capacity. …*
>
> *What about the prospects for lower prices under the proposed market reforms? As explained above, simply switching to a discriminatory auction and encouraging bilateral trading is unlikely to drive prices. No matter what forum they are trading in, companies will not sell at prices that are lower than what they think the market will bear. If the new system discourages entry, the prospects for lower prices may be even dimmer than under the current system. Unfortunately, the reforms do nothing to address the small number of firms and high concentration levels in the industry, and those factors most likely have much more to do with the high prices than the organization of the market."*

Similar arguments can be found in Harbord and McCoy (2000), and in Hogan (2000). Ofgem <u>alone</u> however, places much of the blame for the problems of the England and Wales electricity market on the 'special nature' of electricity, rather than on the issues of market structure and imperfect market design, where every other economist who has studied these issues thinks they belong:

> *"The physical and economic characteristics of electricity make it possible for participants with very small market shares (measured either on an output or capacity basis) who are offering to sell electricity close to 'real time' to set or substantially influence prices, for example by changing their bidding strategies or by withholding generation capacity. …The reason for this lies in the special nature of electricity. It requires moment to moment balancing of a system for a product that it is impossible to store. … It is this feature, combined with the short-term inelasticity of both generation and demand that makes it possible for a generator that is not obviously dominant to exercise substantial market power, and there are many examples of this exercise of substantial market power by both large and small generators. This has been made easier by some special and injurious features of the Pool, but its fundamental cause arises from the special features of electricity itself. "*

Restructured electricity markets are now amongst the most intensively studied markets in the world. In the past decade, dozens of economists have been at work developing both the theoretical analysis of competition in these markets, and the empirical and simulation approaches to addressing the market power issues which have arisen. All of these economists recognise the unique and interesting features of restructured or deregulated electricity wholesale electricity markets, which have important implications for both good market design and for appropriate forms of regulatory oversight.[103] Co-ordination of generation and transmission, and continuous and instantaneous market-clearing, means that completely decentralised solutions have not been available.[104] Transmission limits and constraints can and do give rise to problems of local market power. The absence of demand-side bidding, and consequent low demand elasticities in most of these markets has exacerbated the problems of market power exercised by large firms.

None of these features, however, means that electricity markets differ qualitatively from other markets with respect to the analysis, diagnosis, or control of abuses of market power. On the contrary, the large theoretical and empirical literature which now exists on these subjects is testimony to the efficacy of traditional economic analysis in this area. While Ofgem are correct in pointing to the particular market power problems which can and do arise in electricity networks, and which may have no immediate counterparts in non-network industries, these can and should be dealt with by normal competition policy rules, once the nature of these issues has been correctly diagnosed.

Ofgem's proposed licence condition prohibiting abuse of market power by small firms therefore finds no rigorous basis in the economic analysis of electricity

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103 As Newbery (1999) has pointed out, this partly accounts for their intellectual fascination with the subject.

104 Wilson (1999).

markets. We have demonstrated in this report that the claim that the unique or special features of electricity markets make them particularly vulnerable to abuses of market power by 'small' firms (i.e. firms that are not dominant in the relevant market), is without economic foundation. Where specific market power issues do arise in electricity markets, these can be dealt with by standard competition policy rules, at least when a sensible and economically coherent approach to market definition is taken. There is no basis for the claim that electricity markets require special regulatory rules to control abuses of market power by small firms.

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