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Modeling for Market Design
Methodology and Case Studies from Energy Markets

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For my family
Abstract

Modeling for Market Design, by John Anthony Curzon Price

The aim of this thesis is to critically examine the economic modeling tools available to policy makers as they attempt to establish the rules and structures necessary for the success of market-based regulation of energy natural monopolies. Four case studies each consider a modeling style applied to a specific energy market design question.

Economic theory has seen a burgeoning success in its analysis of mechanism design problems, in particular in uncovering the fundamental causes of regulatory performance as asymmetric information and imperfectly aligned agent interests. These advances should naturally illuminate the policy problems of regulating decentralised utilities. What are the modeling methods appropriate in making mechanism design relevant to everyday microeconomic policy decisions?

Chapter 1 summarises the successes and failures of the models considered, and concludes with a statement of support for methodological diversity.

Chapter 2 builds an "Applied Theory" model of an auction format proposed by the UK energy regulator with the aim of providing a promised level of revenue to the natural monopolist while instituting a market mechanism. The model employs Nash equilibrium reasoning to undermine confidence in the suitability of the proposed mechanism. Despite the very limited representational realism of the model, it provides a strong prima facie case against the mechanism.

Chapter 3 examines the reasons for a particular exercise of market power common in the UK power market: electricity suppliers have offered power for sale at a cost lower than the spot price of their inputs would suggest is efficient. Two explanations, one drawn from a large-scale statistical analysis and another grounded in minute examination of institutional and empirical detail, are contrasted. While the empirical method successfully uncovers plausible explanations of behaviour, it remains relatively silent on forecasting behaviour under different policy environments.

Chapter 4 uses experimental methods to examine the properties of uniform and discriminatory auctions in the context of the UK gas storage market. The experimental method generates useful conclusions for a policy maker—including one which has the potential to diffuse regulatory conflict. However, direct empirical validation of the results, providing support for the belief that the laboratory setting is a good representation of the market, is not available. Moreover, the complexity of the mechanisms modeled is limited.

Chapter 5 surveys the applied use of large-scale micro-economic simulation models in policy making. The structural-econometric approach is contrasted to an "applied-theory" approach. Both of these are contrasted to the use of agent-based simulations. While little success is found in the application of these to UK power policy, an application to UK medical intern markets suggests that these methods should live up to their promise in the context of energy natural monopoly regulation.
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Chapter 3 is derived from two prior pieces of work. The first is my critique of the statistical analysis of the E&W ESI that was carried out by Wolak and Patrick. The second is a collaboration with David Harbord when working at Lexecon Ltd, the London-based economic consultancy. The origins of this work are in a “lobby piece” commissioned by RJB Mining, the operator of most of the UK’s coal mines. Thanks to David Harbord, Lexecon Ltd and RJB Mining.

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Chapter 1

Introduction

1.1 Market Design in Energy Natural Monopolies

In Britain and the United States, the energy natural monopolies of gas and electricity supply have increasingly been regulated under decentralised, "market"-based regimes. The aim of this thesis is to critically examine the economic modeling tools available to policy makers as they attempt to establish the rules and structures necessary for the success of market-based regulation. Four case studies each consider a modeling style applied to a specific energy market design question. This introduction provides background to the modeling needs arising from regulation of the energy natural monopolies and brings together the lessons of the four case studies.

1. Other countries have also experimented with "market" regulation. Scandinavia has decentralised its electricity grid; Spain and Germany have moved towards more market-based regimes in electricity. France has largely resisted the "Anglo-Saxon model" in both gas and electricity. Gilbert and Kahn (1996) provide an international overview.
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1.1.1 The Need for Market Design Tools

Electricity and gas supply are characterised by a number of factors which make them naturally regulated activities:

- large sunk costs and natural monopoly,
- political sensitivity of end-user prices,
- political sensitivity of low probability "catastrophic" events, like shortages and accidents,
- inability to escape regulation, for example through de-localisation of production or consumption.\(^2\)

Gas and electricity supply have almost always been regulated, whether through direct state ownership and control, or through rules and regulations. The history of energy natural monopolies in the US and the UK can be divided into four broad periods:

- relative laissez-faire and \textit{ad hoc} regulation
- increasingly blunt price and rate of return regulation
- a perception of crisis, with under-investment, poor service, unwieldy management
- decentralised, market based, re-regulation.

\(^2\)This last characteristic needs to be added, I think, to differentiate the style of regulation that is imposed on energy natural monopolies from the style afforded to pharmaceutical companies, which otherwise satisfy the first three criteria.
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The last period is the one which is associated with deregulation and an active search for market mechanisms to replace command and control administration.\(^3\)

The phase of price and rate of return regulation has been relatively long-lived in all the energy natural monopolies; it is still the mode of regulation for most energy systems in most of the world. The natural monopolies in energy are characterised by large long-lived sunk investments (pipelines, power stations, power grids), and these are often backed in the financial markets by long term contracts. Slow response to the incentives instituted by regulation will therefore be typical of these markets.\(^4\) This fact underlines the importance of good analysis in the preparation of the details of energy policy—the inertia of energy systems is very great, and mistakes may come to light a long time after the behaviour that caused them. Careful modeling is required to ensure, as far as possible, that perverse incentives do not over the long run undermine the goals of energy policy.

The rate of return and tariff-based regulation of the old regulatory regimes led to economic modeling that concentrated on welfare issues without particular concern for the incentives required to implement the welfare results.\(^5\)

\(^{3}\)Some historical background to energy regulation is provided in Robinson (1993), Cas- taneda (1999) and Hamaidjian (1993).

\(^{4}\)This thesis does not consider the broad question of the desirability of decentralised regulation. The jury is far from decided on the issue of “Anglo-Saxon” regulation against the French model of state ownership and regulation of vertically integrated monopolies. The decentralised model is too young to have proven beyond reasonable doubt that it can sustain appropriate investment levels and deliver acceptable prices through all the vicissitudes that energy supplies eventually face. The analysis of Chapter 3 suggests that much of the investment in gas fired plant in the UK in the 1990s was inappropriate and socially wasteful. Newbery (1995) makes a similar claim.

\(^{5}\)Maurice Boiteux wrote his pioneering contributions to the theory of Ramsay-Boiteux pricing (Boiteux 1956) while head of economics research at the Electricité de France. Optimal pricing for a budget constrained natural monopoly was a very practical question
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The new style of regulation has prompted a demand on the part of policy makers for a class of modeling tools, new in the world of energy regulation, that can represent and predict the behaviour of regulated agents under different incentive schemes.

1.2 Modeling Case Studies

Much of modern micro-economics focuses on the problem of forecasting agent behaviour under complex incentive schemes: the “applied theory” models of industrial organisation, structural micro-econometrics, laboratory-based experimental economics, and agent-based modeling all try to provide detailed predictions of the behaviour of economic agents in complex settings. This thesis takes four case studies of the way that different modeling styles have been applied to gas and electricity market design in the last 10 years. In each case study, the focus has been on an analysis of how useful each model has been (or could have been) to a policy maker. A summary of the models considered is presented in Table 1.1.

The “Model Types” are categorised as:

* **Applied Theory** —the sort of model which represents the structure of incentives and the form of competition in a particular market situation, and generates behavioural predictions by deducing equilibrium.

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5There is some degree of arbitrariness in the categorisation scheme. The line between “Applied Theory” and “Structural Econometrics” models is not clear, nor is the line between these and “Empirical/Institutional” models. All of these use some mixture of filed data and theoretical reasoning to generate their conclusions.
### Table 1.1: Summary of modeling case studies

| Model Type            | Reference                     | Chapter | Application          | Practical Use | Positive                                      | Negative                                                                 |
|-----------------------|-------------------------------|---------|----------------------|----------------|------------------------------------------------|
| Applied Theory        | Fehr and Herbold, 1993a       | Chapter 2 | UK Power Market      | 7              | Uncovers structural flaws                      | Lack of realism leads to doubts over predictions                          |
|                       |                               |         | UK Gas Market        | 5              | Debunks "armchair theorising"                  | Offers no constructive solution, unrealistic environment                 |
| Structural Econometric| Green and Newbery 1992        | Chapter 3 | UK Power Market      | 6              | Good market representation                     | Arbitrary model calibration                                              |
|                       | Wicks and Patrick 1997        |         | UK Power Market      | 5              | Distils a huge data set                        | Causal model questionable                                                |
| Empirical/institutional| Laboratory                   | Chapter 4 | UK Power and Gas Market | 5              | Ex-post explanatory                             | Lack of prescriptive power                                              |
|                       | Bunn and Oliveira 2001        |         | UK Power Market      | 4              | Very detailed simulations                      | Lack of empirical validation                                              |
|                       | Unver 2001                    |         | UK Medical Intermarket | 7              | Compelling Explanation of Institutional Structure | Exploratory more than prescriptive model                                |

**Structural Econometrics** is a style of statistical analysis which aims to parametrise theoretical models, and to use the parametrised models to simulate behavioural or aggregate predictions.

**Empirical/Institutional** modeling considers in great detail the institutional details of a market—in this case the structure of contracts—and uses simple reasoning about incentives to establish behavioural explanations.

**Laboratory Simulation** borrows from the techniques of experimental psychology to reproduce the relevant aspects of decision-making in laboratory conditions; the behaviour of economic agents is inferred from the behaviour of laboratory subjects.

**Agent-Based** modeling uses techniques from computer science and artificial intelligence to simulate the behaviour of boundedly-rational agents.
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responding to incentive in simulated environments.

Column five of Table 1.1 provides a subjective, judgement-based ranking of the policy usefulness of the models considered. The ranking is based on an imaginary scale of 1 to 10. For a score of 5 or more it is sufficient that a model has been used by an economic agent in the policy process itself (in the case of Unver (2001), it is judged that the model could have been used in the face of a relevant policy question). A score above 5 is given to models that also offer constructive policy solutions, and a score above 6 is given to models whose predictions or prescriptions are judged to be particularly well-founded.

The ranking is subjective: it reflects the policy-bias of this enquiry, and also the particular models that have been studied here; there is no implication intended that a given approach intrinsically suffers any particular drawbacks. Sections 1.2.1 to 1.2.5 summarise the models considered and their lessons.

1.2.1 Applied Theory

Chapter 2 is the most extensive applied theory exposition of this thesis, and Chapter 5 contains a detailed exposition of the applied theory model of Fehr and Harbord (1993). Chapter 2 analyses a policy proposal for a "revenue maximising" auction. The UK energy regulator proposed this during a negotiation with the natural monopoly supplier as a way of guaranteeing revenues that had previously been promised, while also instituting a market-based mechanism for allocation.

The model of the revenue maximising auction earns a subjective "5" score:
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Use in the policy process: it was used by the natural monopolist in the regulatory process.

Constructive results: its conclusions are almost entirely negative, showing only that the proposed auction is unlikely to have the intended effects. It offers no help to the policy maker trying to solve the problem of guaranteeing revenues while instituting a market mechanism. Partly, the lack of any constructive policy message comes from the fact that the model is shown to have many Nash equilibria; in the absence of a method for selecting amongst multiple equilibria, predictive power from the model is reduced.

Persuasiveness: the model is unrealistic in various parts: agents are perfectly informed, and their behaviour is perfectly rational. It is difficult to assess the practical import of a lack of realism—all models must be unrealistic to some extent—but such glaring omissions cast doubt on results.

In contrast, the Fehr and Harbord (1993) model earns a subjective “7”:

Use in the policy process: it has been widely used and cited in the policy process.

Constructive results: the model offers a re-design of the auction format or a change in the ownership structure of the industry to resolve the problems it identifies.

Persuasiveness: The model suffers a certain lack of realism: the “pool game” modeled is very much simpler than the pricing mechanism that
existed in the UK power market. The representation of the supply-side of the market is greatly simplified. The players are assumed to be perfectly rational, and are even thought to compute optimal mixed strategies under certain demand conditions. The players are analysed as playing a one-shot game, when the reality of the UK power market is that they frequently repeat an indefinitely repeated game. All this lack of realism reduces the conviction one can have in the predictions and prescriptions. Nevertheless, the prescriptions are relatively general: "more producers would be better for efficiency" and "Vickrey (Vickrey 1961) auctions are less manipulable than uniform auctions"; they are strengthened in this context by the model which takes some of the industrial peculiarities of the case into account.

1.2.2 Structural Econometric

Chapter 3 contains a critique of the structural econometric model of the UK power market of Wolak and Patrick (1997) (score of 5), and Chapter 5 contains an exposition of the structural econometric model of the UK power market of Green and Newbery (1992) (score of 6). The latter is the more successful of the two, because Wolak and Patrick (1997) fails to be causally persuasive (as is argued in Chapter 3). Both models attempt to identify and isolate the structure of imperfect competition in the UK power market, and Green and Newbery (1992) simulate their model to identify the benefit of different ownership structures. They argue for a break-up of the two major
CHAPTER 1. INTRODUCTION

generators into at least five companies.\(^7\)

**Use in the policy process**: it has been widely used and cited in the policy process.

**Constructive results**: The model offers a change in the ownership structure of the industry to resolve the problems it identifies.

**Persuasiveness**: Chapter 5 criticises Green and Newbery (1992) for forcing the UK Power market into the straight-jacket of a piece of existing theory. This leads the authors to a number of arbitrary, unmodeled choices which together weaken the results they offer.

### 1.2.3 Empirical Institutional

The institutional analysis of Chapter 3 (which receives a subjective score of 5) takes a very detailed look at the sometimes complex contractual arrangements prevalent in the UK Gas and Electricity markets. In particular, the chapter examines these contracts at the point at which the two markets most overlapped in the 1990s—the long term, “back-to-back” contracts that tied up the finances of new Combined Cycle Gas Turbine (CCGT) gener-

\(^7\)Both Green and Newbery (1992) and Fehr and Harbord (1993) recommend a fundamental change in the ownership structure only a few years after the start of the privatisation that established the industry structure that they criticise. From a modeling perspective, one might hope that had the policy maker had better forecasting tools, she might have started with a better ownership structure. These would be unfounded hopes. The original plan had been to have five competing generators. However, the government found no support for the private ownership of nuclear capacity amongst investors (because of the risk of huge liability). Therefore, it tried to sweeten the nuclear pill by offering for sale two large generating companies. When even these were insufficient to lure private investors, it was too late to revert to the previous ownership structure ... Accident has its part to play in design. This accidental history of the power deregulation is told in Robinson (1993).
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ating plant. The chapter concludes that a proper understanding of these contractual relationships is sufficient to account for the low pricing relative to coal generators of gas generators in the power market. The analytical technique used to establish this argument is “Institutional” in that it rests on very detailed knowledge of the relationships between players, and very little on complex interactions of incentives: the incentives of the players are straight-forward once the institutional context is understood. This is at the opposite extreme of most “applied theory” models, which tend to abstract from institutional detail and instead concentrate on often difficult equilibrium reasoning.

Use in the policy process: this analysis was used by one of the players to make a case for coal subsidies; as a style of analysis, it is probably the most prevalent in the policy process;

Constructive results: the analysis is not constructive; it cautions against the conclusions suggested by Wolak and Patrick (1997), but offers no clear remedies. The reason for this goes to the heart of a common limitation of this type of analysis: while it is good at ex post explanation of behaviour, it does not offer any way to predict behaviour under different conditions.

Persuasiveness: the analysis gives necessary conditions for a particular market outcome, and in this the conclusions are well founded in the institutional facts and in the simple incentives-based reasoning. This is “good enough” as a critique of alternative accounts of the same out-
comes; however, it does not allow more ambitious and prescriptive conclusions.

1.2.4 Laboratory Simulation

Chapter 4.1 looks at a specific auction design issue faced by the UK gas market regulator in 1999, and contributes to the general debate over the efficiency and revenue rankings of uniform and discriminatory auctions. The technique used is to try to reproduce the salient aspects of the market to be designed in a simulated environment with agents being played by human subjects—in this case taken from the University College London post-graduate student population. The technique recognises one of the serious limitations of most “applied theory” in reducing the onus of rationality placed on agents: the prediction of a laboratory simulation is determined by the behaviour of the subjects.

Use in the policy process: this experiment was used in the market design process.

Constructive results: the analysis produces some clear and possibly constructive conclusions; it concludes that the regulator and the natural monopolist may well not be in conflict over auction choice, as long as they can agree on the relevant facts about the market.

Persuasiveness: how good a model of the target environment is the laboratory setting? The “environment” needs to be appropriately represented, and in this, the laboratory is open to the same types of criticism
as other models are: is it right to represent the market interactions of a few large firms as a limited number of repetitions between a few students? Do players have appropriate levels of information about other players and the strategic setting? Are post-graduates playing for £25 going to behave similarly to humans within corporations where much may be at stake for the company, but little for the person or team making the decision? ... Confidence in the foundations of conclusions based on experimental methods will come from an accumulation of evidence, from the establishment of (and adherence to) rules of "sound practice". Ultimately, one will want to see clear correlations between field-data and experimental data.\(^8\) Despite outstanding questions that are specific to laboratory modeling and to the particular way this market was modeled, the conclusions seem well-founded, and pass a basic set of statistical significance tests.

1.2.5 Agent-based Simulation

The experimental method can produce relevant, constructive and strong results. It nevertheless has limitations: the time, effort and money needed to extract the conclusions can be considerable. Moreover, it is not clear how complex and realistic the environment simulation can be made: students need time and repetition to understand a market, and, as a practical matter, it is hard to get concentrated attention from subjects for more than a few

\(^8\)Smith (for example Smith (1985)) and Kagel and Roth (1995)) contain pioneering work in experimental methods, and go some way to establishing "sound practice". The experience of experimental psychologists can also be used. The difficulty and importance of correlating field data and experimental data is noted by Roth (1991).
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hours. This limits the amount of learning that can be achieved, and therefore the complexity of the simulation.

Chapter 5 explores agent-based models as a promising technique to get the best of “Applied Theory” and experimental methods. Agent-based models use computer simulations of both environment and of the learning processes of agents. They are similar to experimental settings in that the environment is modeled and simulated such as to accept agent-input, while the experimental subjects are replaced by some form of artificial intelligence learner. Chapter 5 considers the agent-based modeling of the UK Power market carried out by this author ((Curzon Price 1999) and (Curzon Price 1997)), as well as those of Bunn and Oliveira (2001). These models are ultimately limited in what they achieve. Chapter 5 therefore also considers the agent-based modeling of the matching market for medical interns by Unver (2001). This is a much more successful application of the technique, and provides lessons for future applications to the UK pool.

Use in the policy process: as far as this author knows, the models of Curzon Price (1999) and Bunn and Oliveira (2001) have not been used in the policy process (although a model derived from Bunn and Oliveira (2001) has at least been under consideration by the regulatory authorities—see Footnote 34, Page 173).

Constructive results: the agent models of the pool have not yielded sufficiently strong results to be significantly constructive.

Persuasiveness: Chapter 5 criticises the agent models of the UK pool for being unpersuasive representations of the market.
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However, if we imagine an appropriate market design issue in the market analysed by Unver (2001), it is easy to see that this model could have been all three of used, constructive and well-founded. Agent-based models have the vocation to complement and sometimes replace laboratory studies in the market design process, but (as with all modeling) their application requires judgement, skill and care which have to some extent been missing from the current applications to the UK pool.

1.3 In Praise of Methodological Pluralism

Over ten years ago, Roth (1991) wrote:

> Just as chemical engineers are called upon not merely to understand the principles which govern chemical plants, but to design them, and just as physicians aim not merely to understand the biological causes of disease, but their treatment and prevention, a measure of the success of microeconomics will be the extent to which it becomes the source of practical advice, solidly grounded in well tested theory, on designing the institutions through which we interact with one another.

This thesis is an account of several attempts to live up to the ideal painted by Roth. In the background of the methodological diversity of the thesis has been the question of whether a pragmatic emphasis on policy design has any impact on preferred methods of analysis.

I embarked on this investigation with the prior belief that agent based models would be shown to be the “right sort” of approach to applied market
design, but have finished it with a much greater appreciation that context and question often diversely determine the appropriate method. The “applied theory” of Chapter 2 is good enough to debunk a faulty intuition that could have become policy; it provides high level guidance. The empirical study of Chapter 3 is again good enough to avoid hasty policy conclusions based on a misreading of field data. The laboratory study of behaviour in different auctions of Chapter 4 stands out as a useful, constructive and well-founded contribution to the market design process. Finally, the best-in-class of the agent models considered, Unver (2001), shows that agent-based modeling can indeed live up to its promise for market design.

Table 1.2 summarises the lessons learnt about the ideal context for each modeling style, as well as appropriate caveats.

**Applied Theory** Both cases of “applied theory” were found to be powerful high level guides to intuition—they countered the almost natural beliefs that a proposed rule would maximise revenues, or that a uniform auction would counter market power. This is a valuable role in the policy process, given the amount of policy formulation that is not informed by explicit modeling of the economic context. However, a persistent caveat is the lack of realism in both environment and agent behaviour representation, leading to doubts over the validity of detailed predictions.

**Empirical/Structural** The Empirical/Structural analyses are most successful when determining which of a number of plausible explanations are correct. They are restricted to contexts with high quality data, and
there is always a danger of mis-identifying causes: many causal models are typically consistent with a given data set, and the modeler must judge whether to look for validation beyond a given data set.

**Laboratory** Laboratory models are particularly suited to testing the characteristics of broad classes of proposed mechanisms. Such a context makes for clear experiments with clearly testable hypotheses. The approach is unlikely to be very successful when testing complete and complex market designs, because of the limitations of subjects' abilities to master a context. Moreover, it is not always possible to validate experimental results against field data—indeed, it is often the lack of field data that leads one to experiment—so confidence in the laboratory forecasts must to some extent be based on general accumulated confidence in the method and its rules of good practice.

**Agent Simulations** Agent-based modeling has most to offer the market designer in contexts where the details of the environment and incentives are complex, and in which players cannot be assumed to be rational. Agent-based models face a surmountable challenge of empirical validation similar to that faced by "applied theory" models.

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*One is tempted to get around this problem by using industry insiders as subjects. Charles Plott tells a cautionary tale in this context: the story of an early game theory experiment in which the same game was "framed" in the context of a military problem, a business problem and a political problem. Experts from the three fields were asked to play the three versions of the game. It is said that the experts did very well, but just as long as the game was not framed in the context of their own expertise. One is tempted to explain the finding with the hypothesis that rules honed to a specific context are thought to hold in general, as long as the context does not change too much. In an unfamiliar context, thought replaces the application of rules of thumb. Thus, the expert can often not tell the difference between a rule that is honed to a specific context and a piece of context-independent understanding, making her an imperfect subject for testing profound rule changes in familiar contexts.*
Is there anything wrong with such methodological diversity? There is a "realist" position in the philosophy of science which would be suspicious of methodological pluralism: scientific models aim to represent an underlying reality so only one representation can be the "right" one. However, this sort of empirical realism is challenged by the pragmatic empiricism of Quine:

\[...\] I continue to think of the conceptual scheme of science as a tool, ultimately, for predicting future experience in the light of past experience. Physical objects are conceptually imported into the situation as convenient intermediaries—not by definition in terms of experience, but simply as irreducible posits, comparable, epistemologically, to the gods of Homer... Moreover the abstract entities which are the substance of mathematics... are another posit in the same spirit. Epistemologically these are myths on the same footing with physical objects and gods, neither better nor

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10 This sort of empirical realism is associated with the early Russell, for example Russell (1993 (1914)).
worse except for differences in the degree to which they expedite our dealings with sense experiences. (Quine 1980, page 44)

In Quine's view, a scientific model is any useful calculus that helps us to predict experience. One should not look for further justification of any particular approach or set of assumptions.

In the context of the methodology of market design, this pragmatism is both liberating—in that it encourages the policy maker to be open-minded to all sorts of approaches—and also challenging, in that competence in market design invites mastery of a broad (and broadening) tool-kit of modeling methods.
Chapter 2

The "Revenue Maximising" Auction

2.1 Background

How can a regulator both impose a "quasi-market" mechanism and help a firm meet a revenue target that the regulator has endorsed? The two seem antithetical. During the transition from fiat regulation of utilities to their quasi-market-regulation, this problem often has to be faced. A court, or a previous regulatory ruling, will have allowed investors to expect a safe return; a new quasi-market mechanism can easily undermine a revenue stream, for example by introducing competition, or simply by not allowing monopolistic pricing policies.

This is exactly the problem that OFGAS faced in the winter 1998. In 1996, the Monopolies and Mergers' Commission had ruled that BG plc. was permitted to earn up to £160 million from the operation of its storage busi-
ness.\(^1\) By the winter of 1998, the regulator wanted to find a way of limiting the exercise of BG plc.’s market power in the storage business, and opened discussions with BG Storage on an auction of storage rights. BG Storage made it clear to OFGAS that it considered the MMC revenue permission to be a right\(^2\) and that OFGAS could not therefore impose a mechanism that did not seem to BG Storage to be likely to generate the required revenue without a bruising legal battle. One OFGAS adviser proposed the “Revenue Maximising Auction” (RMA) as the mechanism-design answer to the problem.

This section begins the study of the “Revenue Maximising Auction”. Why study it at all? Although it came to nothing,\(^3\) the problem confronted by OFGAS is often faced when restructuring industries with assets sunk in a regulatory regime of cost recovery\(^4\). Governments might even be tempted to use an RMA in the sale of government securities.\(^5\) Secondly, the analysis suggests some interesting properties of the mechanism: it reduces the multiplicity of equilibria of the multi-unit uniform-price auction, and may eliminate some of the more worrying equilibria from the seller’s perspective. For this reason, it is tentatively proposed that the RMA might be further tested for use in situations in which the multiplicity of equilibria of the auction is particularly damaging—as when frequent repetition allows bidders

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\(^1\)Storage was not the focus of this MMC enquiry into BG plc. It is widely thought in the industry, and even within BG plc., that the storage business was given light treatment because no one had the heart to start another argument.

\(^2\)There continues to be legal fog around whether it is.

\(^3\)The BG plc. vs. OFGAS negotiations took a different turn.

\(^4\)For example, in the US electricity industry, the question of what to do with nuclear investments in more competitive markets. The same issue will arise all over Europe if the Directives on gas and electricity liberalisation are properly implemented.

\(^5\)Governments sometimes bid in their own auctions, which comes to the same thing.
to coordinate on low-value equilibria (as has almost certainly happened in
the UK electricity market (Chapter 3)). Finally, from the viewpoint of ap­
plied mechanism design, this chapter illustrates the use of simple equilibrium
modelling: it is found that the equilibria of an auction intended to maximise
revenue does not have the properties for which the design was proposed. It
does not necessarily generate higher revenues than simple uniform or dis­
criminatory auctions.

2.2 Previous Analyses

The “Revenue Maximising Auction” (RMA) is just a specific instance of a
“menu auction”. These were introduced by Berhneim and Whinston (1986),
and have recently been analysed more extensively in the context of lobby­
ing games, notably in Besley and Coate (1999)and Grossman and Helpman
(1994). Krishna and Ttranaes (1998) provide a diagrammatic exposition of
the Bernheim and Whinston model.

Berhneim and Whinston (1986) propose “menu auctions” as a way of
modelling the allocation process often found in large procurement contracts,
where suppliers can submit complicated partial offers (eg “our firm will do
the scaffolding on this project for $xm”, and “this firm will do half the the
masonry for $ym as long as it also does the asphalting”), and buyers pick
their own preferred set of options from the “menu” they have been presented
with.

As is natural with this sort of application in mind, Berhneim and Whin­
ston (1986) consider “first-price” menu auctions, in which bidders, if selected,
pay their announced offers, and the auctioneer chooses the profit-maximising combination of bids.

Berhneim and Whinston (1986) make a further two assumptions that are less attractive for the case they wish to model. They consider the case of perfectly informed bidders, which seems extreme (but I shall consider only this case as well). They impose a restriction on bids that these should be “$k_i$ truthful”, meaning that all bids should be translations of $k_i$ units of the truthful valuation functions. This refinement (Berhneim and Whinston 1986, page 3) allows them to say that all equilibria are efficient. Moreover, they establish that these bidding functions provide coalition-proof equilibria.\footnote{Krishna and Ttranaes (1998) also impose “$k_i$ truthfulness” on the bids, and write (page 6) that: “Each buyer truthfully bids the price at which he would be willing to get $q_j$ units. Truthful bids are regret free; no matter what allocation the buyer obtains, he will not have any regrets if the allocation is made at the bid price.” The justification hinted at for the refinement is that a price taker maximises utility by truthfully revealing his valuation. But this is not relevant to cases in which there are a small enough number of players for the price-taking assumption to be invalid.}

Despite this, one has reason to be uneasy with the restriction. Although the multi-unit discriminatory (first-price) auction remains under-studied, a certain number of results seem accepted. One of these is that the equilibrium bid functions cannot be sloped (see, for example, Anwar (1998), and Reny (1988)). The intuition for the result of Anwar (1998) is clear: imagine that you have submitted a sloped bid, and you are allocated more than one unit; it must be true that you paid more for your first units than your last one. But you could have paid the price of your last unit if you had correctly anticipated the auction and submitted a flat (single-stepped) bid curve. Therefore, any pure-strategy equilibrium of the perfectly informed bidder discriminatory auction must involve flat, single-stepped bid functions.
where it matters. Moreover, Reny (1988) establishes that this auction has a pure-strategy equilibrium. This would suggest that the Bernheim and Whinston assumption will only hold in very specific circumstances.

Already Berhneim and Whinston (1986) suggest that the model might appropriately be employed to analyse the market for influence. This is explored more fully in Grossman and Helpman (1994) and Besley and Coate (1999). The lobbying process is modelled as the following game:

1. Lobby groups, who differ in their preferences over the level of provision of a public good, submit an offer to a (dictatorial) politician relating a level of provision to a utility recompense for the politician;

2. The politician chooses a level of provision of the public good; he receives his own intrinsic valuation plus what utilities are implied by the lobbyists' offers.

3. An equilibrium of the policy process is a state in which: (i) each lobbyist's offer schedule is a best response to the other lobbyists' schedules given the policy choice that is made, and (ii) the policy choice is optimal given the lobbyists' offers.

Unlike the version of Berhneim and Whinston (1986), the models of Grossman and Helpman (1994) and Besley and Coate (1999), do not impose \( k \)-truthfulness on the bidding functions. The menu auction is still "first-price" in that the lobbyists pay the amount that they offer if their offer is selected by the policy-maker. This model has many equilibria.
2.2.1 The contribution of this analysis

The model that I present here is similar to those of Grossman and Helpman (1994) and Besley and Coate (1999). There are three main reasons for an additional analysis of the menu auction model in a "standard" auction context:

1. My model has a uniform-price rule rather than a discriminatory rule. Whereas the discriminatory makes sense in the political games, the uniform is more likely in the regulatory setting that I have in mind here.

2. Besley and Coate (1999) apply this auction to a public allocation good problem. This analysis is for a private good, which brings the mechanism issues to the fore.

3. Besley has suggested that the multiple equilibria in his model are analogous to the multiplicity of equilibria found in the supply-function equilibrium model of Klemperer and Meyer (1989). The analysis below shows the analogy may not be quite so simple. In particular, the multiplicity of supply-function equilibria is analogous to the multiplicity of...

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7 Competition law is usually explicit in its condemnation of price discrimination. Gas and electricity regulators in the UK have taken instances of customers paying different prices for the same good as prima facie evidence of abuse of a dominant position. These same regulators have recently become more open to the virtues of discriminatory auctions, to the point of supporting a discriminatory auction against a proposal for a Vickrey auction for the October 1999 allocation of gas-terminal entry capacity.

8 They have lobbyists bidding politician's utilities for levels of a public good. Whilst the payment method seems unnecessarily cynical (politicians also enjoy the self-respect, glory and attendant benefits of office), the favour asked—the provision of a public good—seems strangely benevolent for a supposedly realpolitik model.

9 This suggestion was made in discussion, at the ESRC Game Theory Conference on Political Economy, June 1999, London.
ity of equilibria of the uniform-price auction (as developed, for example, in Binmore and Swierzbinski (1997)). Moreover, the Klemperer and Meyer model has strategic bidders only on the supply side of the market—demand is exogenous. One of the particularly nice features of the menu-auction is that strategy comes on both sides of the market: bidders do best given each others’ bids and given the objective function of the seller. The analysis presented here suggests that the multiplicity of the menu-auction equilibria will be less serious than the multiplicity of the uniform auction.

4. I present a simple and largely graphical analysis of the two-player case.

2.3 A Model of the “Revenue Maximising Auction” (RMA)

2.3.1 The Model

The auction rules

The steps in the auction process are the following:

1. bidders simultaneously submit a demand schedule;

2. the auctioneer selects a quantity to sell;

3. the bidders pay the price given by the aggregate demand curve at the auctioneer’s chosen quantity;
4. the bidders receive the allocation for which each has bid at the price determined in step 3.

The seller can thus be thought of as being committed to abstaining from price discrimination—this was one of the regulator’s repeated concerns with current practice—but is permitted to behave as a monopolist with the bids induced by the mechanism. The seller does not commit to sell all units of capacity, although she may choose to.

The players

The auctioneer is taken to be a revenue-maximiser with zero costs and a reserve price of \( P_{\text{min}} \) and some capacity constraint at output \( k \).

We consider two bidders, 1 and 2, with quasi-linear profit functions \( \pi_n, (n = 1, 2) \) given by \( \pi_n = R_n(q_n) - p q_n \), where \( q_n \) is the quantity secured by bidder \( n \) in the auction, and \( p \) is the uniform-price selected by the seller.

Information

We assume that the players’ valuations are common knowledge amongst the players. The only uncertainty arises out of the outcomes of the game itself.\(^\text{10}\)

2.3.2 Best Responses

The series of Figures, from Figure 2.1 to Figure 2.4 show how we construct the best responses of a bidder.

\(^{10}\)Why conduct an auction if there is not private information to reveal? This assumption is simply a modelling convenience.
Given $B_1$, what should bidder 2 bid?

Figure 2.1: Best Responses in the Revenue Maximising Auction. Given that bidder 1 has submitted a bid of $B_1$, how ought bidder 2 best react? We show bidder 1's demand in the standard way in the right hand quadrant. We also show bidder 1's "true valuation" of the goods, just to underline the fact that the demand curves are just that—they represent announcements by bidders, not valuations. We represent the auctioneer's capacity constraint—the maximum quantity he could ever sell—as a vertical line at $k$. In the left hand quadrant, we will represent in the Figures below, bidder 2's possible bids. Note that we have reversed the quantity axis of bidder 2's quadrant for greater visual clarity.
Figure 2.2: Best Responses in the Revenue Maximising Auction. In considering how best to respond to a bid of $B_1$, bidder 2 must put himself in the shoes of the auctioneer and consider how the auctioneer would react to the possible aggregate outcomes. In this figure, we start to construct bidder 2’s minimum response to $B_1$. What are the bids that would make the auctioneer just indifferent to serving both bidder 1 and 2 rather than just bidder 1? Given $B_1$, we know that a revenue given by the shaded area is always attainable by the auctioneer. The shaded area shows the revenue that a monopolist would attain if faced by the demand curve $B_1$. If bidder 2 submits a demand that allows the auctioneer to just achieve that same revenue level as this, then the auctioneer will be indifferent between serving bidders 1 and 2 and just serving bidder 1. The rectangular hyperbola $RH_1$ shows all price/quantity combinations that will generate the same revenue for the auctioneer as that achieved by serving only bidder 1. Hence, any bid by bidder 2 that leads the auctioneer to select a point above and to the right of the rectangular hyperbola $RH_1$ will lead to some allocation being made to bidder 2, since these points all yield the same revenue as the case with no allocation to bidder 2. Bidder 2 thus knows that he must at least bid such as to put the auctioneer above that rectangular hyperbola to be in the running for any allocation at all.
The locus of points that just put bidder 2 "in the running" To be in the running for an allocation "q", bidder 2 must offer the seller a price and quantity that when combined with B1 will offer the seller higher revenues than serving bidder 1 alone.

Figure 2.3: The minimal acceptable bids that, following the logic of Figure 2.2, bidder 2 must make to be in the running at all is represented in the left hand quadrant. The “minimal bid frontier” is constructed by taking the distance between $B_1$ and $R H_1$. If bidder 2 offers the auctioneer any point on a demand curve above and to the left of this frontier, then the auctioneer can construct an allocation which he prefers to just serving bidder 1.
The locus of points such that the sum of the 2 bids is just equal to the amount on sale - there is no point in bidder 2 exceeding this bid.

The seller has a maximum of k units to sell.

Figure 2.4: We show the impact of the capacity constraint on 2’s acceptable responses. The auctioneer cannot sell more than k units. At the lower prices shown in Figure 2.3, allocations for 1 and 2 can come to sum to more than k units, and are therefore not attainable by the auctioneer. At every price, allocations for 1 and 2 must not sum to more than k units. We show this new constraint on 2’s bids as the “curtailment constraint” in the left hand quadrant. Bidder 2 bids as if bids greater than the curtailment constraint are scaled back such as to make the sum of demands equal to k.
Figure 2.5: The set of responses on the part of bidder 2 to bidder 1’s demand that lead to some allocation being made to him are thus made up of all bids with points within the shaded area. The explanations of Figures 2.2 and 2.3 establish that bids must be above and to the left of the “minimal-bid constraint”. The explanation of Figure 2.4 establishes that the bid must be to the right of the “curtailment constraint".
Figure 2.6: Bidder 2's profits are increasing in quantity and falling in price, so that he will prefer points that are low and to the left in the left-hand quadrant. Bidder 2's preferred allocation, given the demand $B_1$, will therefore lie somewhere on the bold frontier. Where exactly that is will depend on his specific preferences. The figure shows three types of bidder 2: the "small" bidder has profit contours such that his best response to $B_1$ is on the "minimal-bid constraint"; the "medium bidder" has profit contours such that his best response is on the "curtailment constraint" and the "big bidder" has profit contours such that his best response is to demand the entire capacity on offer.
CHAPTER 2. THE "REVENUE MAXIMISING" AUCTION

Best response for the small buyer

The small buyer is defined as one who is sufficiently small for his best response to be at a quantity such that the aggregate demand does not exhaust capacity. This is shown in Figure 2.6 in the fact that his profit contours are tangential to the minimum-bid constraint. The capacity constraint is not binding, but the minimum-bid constraint is. It is clear by inspection of Figure 2.6 that in such cases the best response to any $B_i$ will be a bid function that induces the seller to opt for a lower revenue maximising price than $p_i^*$. Note that the small buyer exaggerates his demand at every price—he is an anti-shader.

The medium-sized buyer

The medium-sized buyer has the tangency of his profit contours on the curtailment constraint. His best response to $B_i$ might be to induce a price higher or lower or identical $p_i^*$, depending on the size of his demand and on the slope of the curtailment constraint. However, it is clear by inspection that the best response will lead to a quantity demanded that is smaller than the "truthful" quantity at any induced price. Hence, the medium-sized buyer will shade his bids.

The big buyer

Given $B_i$, the big buyer wants to bid a price sufficient to secure the entire capacity $k$. Note that if a buyer is "big" at a price $p_i^*$, then he is "big" at all prices below that.
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2.3.3 Equilibria

Pure-strategy equilibria are characterised for different types of bidders: two medium, two small and two large. The driving intuition of these equilibria is that the buyers collectively face a seller who will act as a monopolist, pricing where the aggregate bid function has unit elasticity. The buyers are therefore engaged in finding bids whose sum has unit elasticity at points from which they have no incentive to deviate.

Two Medium Buyers

A pure-strategy Nash equilibrium exists whenever the following conditions are met:

1. Each bid function is a best response to the other’s bid function given that some price $p^*$ is selected by the auctioneer;

2. The seller chooses $p^*$ as the revenue-maximising price given the best response bid functions.

The following algorithm determines whether there is a Nash equilibrium at a chosen price and allocation. Existence at any particular price and quantity is found to depend on the exact nature of the bidder’s preferences.

1. Choose a price for the equilibrium, say $p^*$;

2. Choose a quantity for player 1 at equilibrium, say $q_1^*$;

11The other possible cases—a small and a medium, a medium and a large—are easily seen to collapse into the previously analysed cases.
3. Determine the implied quantity for player 2 at equilibrium, \( q_2^* = k - q_1^* \)
(remember that neither player is small, \textit{ex hypothesi});

4. Fix the slope of 1's bid function at \((q_2^*, p^*)\) such that selling \( q_2^* \) at \( p^* \) is
2's preferred feasible point; note that when player 1 fixes the slope of her bid function, she determines the slope of 2's curtailment constraint.

5. Build 2's bid function given that (i) it must pass through \((q_2^*, p^*)\) and
that its slope at \((q_1^*, p^*)\) is such that selling \( q_1^* \) at \( p^* \) is 1's preferred feasible point;

6. The steps above ensure that bid functions are best response to each
other and have \((k, p^*)\) as the point preferred by the bidders. This
construction is represented in Figure 2.7. We next ensure that \( p^* \) this
is also the auctioneer's preferred price point;

7. We need to ensure that marginal revenue is equal to marginal cost \((p_{\text{min}}
at \( k \); we can imagine an extreme-case construction of the bid functions
that ensures this: we make both of them flat just above \( p^* \), and vertical
just below \( p^* \)—simple step functions. Whilst this will certainly satisfy
the condition that \((k, p^*)\) is the point preferred by the auctioneer, it
may lead to the bid functions no longer being best responses to each
other.

8. Whenever we can get "close enough" to constructing these kinked bid
functions, we have a Nash equilibrium of the two medium buyers game;

9. We can get "close enough" if:
(a) The aggregate bid function has unit elasticity at \((k, p^*)\), so that there is no incentive for the auctioneer to prefer a lower (or higher) price and higher (or lower) volume;

(b) The bid functions can be made elastic above \(p^*\) and inelastic below, so that the auctioneer has the correct incentives to select \((k, p^*)\);

Figure 2.7: Steps 4 and 5 of the algorithm to construct equilibrium bids. Starting with player 2’s isoprofit shown, player 1 can determine the bid that will make player 2 opt for \((q_2^*, p^*)\). The curtailment constraint induced by player 1’s bid is shown as the heavy dash-dot line in the left hand quadrant. In order to make player 1’s bid a best response to player 2’s bid, player 2 must submit a bid that will be a tangent to player 1’s isoprofit at \(kq_2^*\) units and at a price of \(p^*\). The curtailment constraint that this induces is shown as the dotted line in the right hand quadrant.

Note that restrictions are imposed on the slopes of the bid functions in constructing the best responses (steps 4 and 5), so satisfying the unit elasticity condition (9a) on the aggregate will not be possible in general. This is the sense in which the RMA does reduce the multiplicity of the ordinary uniform-price auction. Bids that satisfy the conditions of Steps 4
and 5 can in general be constructed, and this is the reasoning that leads to
the discovery of multiple equilibria in the standard uniform-price auction,
as shown for example in Klemperer and Meyer (1989) and Binmore and
Swierzbinski (1997).

The algorithm shows that not every allocation at every price can be sup­
ported in (pure-strategy) equilibrium. We could ask whether an equilibrium
can always be found for a given allocation, regardless of the price; or if one
could be found for a given price, regardless of the allocation. The answer
depends on the specific form of the bidder's preference functions. The algo­
rithm below describes a sufficient condition for the specific case of quasi-linear
profit functions for both bidders.

1. Consider the efficient allocation, \((q_1^{\text{e}}, q_2^{\text{e}})\);

2. Determine the slope of the bid functions tangential to the iso-profit
functions at \((q_1^{\text{e}}, p_{\text{min}})\) and \((q_2^{\text{e}}, p_{\text{min}})\);

3. If the elasticity of the sum of these bid functions is less than unity,
then:

   (a) There will be an equilibrium at some price between the efficient
       price and \(p_{\text{min}}\) with efficient allocations;

   (b) There will be a range of prices between \(p_{\text{min}}\) and a price below the
       efficient price for which equilibria exist at quantities other than
       the efficient allocations.
The way that this procedure operates in determining a sufficient condition\footnote{The reason that this is not a necessary condition is that we can imagine that at \((q^*_1, p_{\text{min}})\) and \((q^*_2, p_{\text{min}})\), the slopes of the bid functions imply an aggregate elasticity greater than 1. We now know that there is no efficient equilibrium of the RMA. But there may still be inefficient equilibria at different quantities: that depends on the rate at which the profit contours of one bidder change slope as one considers all the "k-apart" allocations for a given price.} for the existence of pure-strategy equilibria of the RMA is demonstrated diagrammatically in Figure 2.8.

![Figure 2.8: Equilibria, if any exist in the two medium buyer case, should be sought in the shaded area. Under quasi-linear profit functions, profit contours become steeper as one moves vertically below the true value curve, and shallower as one moves horizontally towards the true value curve. At the competitive price and efficient allocation, the profit contours are flat. If they are steep enough vertically below this point, then it will be possible to find an equilibrium.](image)

The core of the argument is that, for any given quantity, the profit contours on a quasi-linear profit function get progressively steeper as the price falls.\footnote{Quasi-linearity is a sufficient condition for this to obtain If \(\pi_1(p, q) = R(q_i) - pq_i\), then, for a fixed level of profit, \(dp/dq_1 = (R'(q_1) - p)/q_1\). So, for a fixed quantity \(\bar{q}_1\), \(dp/dq_1\) can only increase as \(p\) falls.} Hence, if the slopes of the profit contours at the lowest price are
steeper than required for the strategic auctioneer to select that price and allocation, then at some point before they become too shallow, they will allow for an aggregate bid function with unit elasticity at the chosen allocation.

Note that the efficient allocation at the truthfully revealing price, in which the players' true valuations sum to \( k \), cannot be a (pure-strategy) equilibrium of the RMA. We know that the slope of the preference curves is infinite for both players; an equilibrium therefore could not have the slope of the sum of the bid function equal to 1.

Two Small Buyers

The only pure-strategy Nash equilibrium of this game occurs at \( p_1^* = p_2^* = p_{\text{min}} \). Any \( B_1 \) such that \( p_1^* > p_{\text{min}} \) will induce a bid \( B_2 \) that leads to a lower price being selected, and a quantity purchased by 2 somewhere along the revenue constraint. Thus, \( B_1 \) and \( B_2 \) cannot be best responses to each other as long as \( p_1^* \neq p_2^* \). This can only occur when neither \( p_1^* \) nor \( p_2^* \) can fall, which is only possible at \( p_{\text{min}} \). This reasoning follows entirely from the fact that a small bidder wants to induce the seller to accept a lower price.\(^{14}\)

It might be a surprise that the "monopolist's" pricing rule of the RMA cannot protect the seller's revenue when there is over-capacity. One thinks of the ordinary (textbook) monopolist as setting an optimal price and then keeping the relevant amount of capacity out of the market. So why does the RMA yield the reserve price where the textbook monopolist would have been able to set a profit maximising price? The only difference is that the textbook

\(^{14}\)As the price falls, a bidder's demand may rise sufficiently for this to turn into a case of two medium bidders.
monopolist does not face strategic buyers. A monopolist committed to setting a single price and facing no capacity constraint, facing strategic buyers with an ability to commit to offers, cannot exercise monopoly power—the buyers will "sterilise" the seller's monopoly via their bids.

In the case of two small buyers, the RMA does not produce higher revenues than the uniform auction. It therefore fails in its intended goal of raising "permitted" revenues, and offers no clear advantage over standard rules. The seller would prefer to commit to higher reserve price (possibly upward-sloping\(^{15}\) rather than to the RMA pricing rule.

**Two Large Buyers**

Figure 2.6 shows that if bidder 2 is "Large" at price \(p_1^*\), then his best response is to offer a bid with a higher price selected by the buyer than \(p_1^*\), call it \(p_2^{++}\). If bidder 1, in turn, is “Large” at \(p_2^{++}\), then 1 too will submit a bid with a higher price selected by the buyer. Where does this "shouting louder than my competitor" end? There will be some lowest price \(p_2^{++}\) or \(p_1^{++}\) at which either 2 or 1 becomes a "medium" bidder, call it \(p_2^{+-}\) or \(p_1^{+-}\).\(^{16}\)

As soon as we have reached a price at which one player has become a “medium” bidder, then the remaining “large” bidder can make an unbeatable offer for the entire capacity. The remaining large bidder wins the object at

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\(^{15}\)Binmore and Swierzbinski (1997) consider the advantages of the seller committing himself to an upward sloping reserve price schedule. The RMA can be thought of as generating an endogenous upwardly sloping reserve price function.

\(^{16}\)There may not be such a price, or there may be two (for the case of symmetric bidders). There will be none if both demand curves are vertical at a quantity greater than or equal to \(k\). In this case, we know that the bidders place no value on an amount smaller than \(k\). This effectively effectively becomes a single unit auction. In the case in which both players simultaneously move to the "medium" regime, we are back in the case of Subsection 2.3.3.
the price which first makes the other bidder "medium". This outcome thus has the feel of a "second price" result: the entire capacity is secured by the high-valuation bidder for the highest rejected offer.

2.4 Conclusion

The primary question addressed in this chapter is whether the intuition that an RMA will raise greater revenue than a uniform auction holds up to careful scrutiny. The analysis shows that the intuition which led the regulator to propose an RMA is faulty, and so casts doubt on the usefulness of the mechanism. The primary conclusion of the analysis is therefore almost entirely negative—not constructive solution to the problem of guaranteeing revenue for stranded assets under a market mechanism is suggested. The RMA does not seem to be well-suited to its stated goal of maximising revenues, because strategic bidders can sterilise the effects of the monopoly pricing rule.\(^{17}\) The analysis of the pure-strategy equilibria do not provide any \textit{a priori} grounds for the belief that more revenues will be raised from an RMA than from a uniform auction—in both cases there is an equilibrium selection problem. There obviously exist equilibria of the uniform that revenue-dominate equilibria of the RMA.

However, the RMA does have fewer equilibria than the uniform auction. This may in itself make it an attractive candidate for a multi-unit uniform auction. Binmore and Swierzbinski (1997) provide a method of constructing equilibria of the multi-unit uniform. Their method shows that (with

\(^{17}\)These concluding remarks must be taken as being tentative until an analysis under imperfect information has been carried out.
well-behaved profit functions) there will almost always be a set of bidding functions that can sustain any price and allocation. This feature of the uniform makes it particularly unsuited to use in an open outcry, or to conditions in which auctions involving the same players are repeated often (as in the new electricity pools (see Chapter 3), because in both cases we would expect to find low price, low revenue, and possibly inefficient equilibria. The RMA may have a vocation in hindering coordination on the worst outcomes of the uniform, even if it does not necessarily help in raising revenues.
Chapter 3

Market Dominance in the
England and Wales Power Pool

3.1 Introduction

The decentralisation of electricity markets has been a playground for applied mechanism designers for the past decade. This sector is therefore a rich source of lessons for applied policy modelling. Market power and how best to regulate it has been a recurrent theme of the economic analysis of these designs; the work of Green and Newbery (1992), Fehr and Harbord (1993) discussed in Chapter 3 are early examples of this, and Anwar (1998) both

\footnote{Good overviews are given in Gilbert and Kahn (1996) and Hunt and Shuttleworth (1996). Curzon Price (1993) remains a good introduction to the original UK reforms. Decentralisation continues faster than publications can keep up with. Good online sources of information include the "Library" pages of Market Design Inc., at http://www.market-design.com.}
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summarises much of this analysis and extends it in important directions. This chapter takes the particular case of Wolak and Patrick (1997)'s statistical analysis of market dominance in the England and Wales electricity supply industry (ESI).\(^2\) It provides an example of the pitfalls involved in having too-slight-a-theoretical model to constrain the analysis, while also having an insufficient grasp of the institutional detail. The pitfalls of straightforward statistical analyses amount to a serious problem in attempts by regulators or pressure groups to seek remedies to the abuse of market dominance through the courts. The chapter ends with some thoughts about the type of empirical work that might alleviate this problem.

3.2 Overview of the England and Wales “Pool”

This section provides essential background to the analysis which follows, and is intended to establish:

- The principles by which the England and Wales deregulated electricity market was designed to select which producers satisfy electricity demand;

- The technical aspects of the industry by which a number of distinct temporal markets for electricity arise which may be broadly categorised as the “base-load”, “mid-merit” and “peak-load” markets.

\(^2\)Wolak and Patrick (1997) has been published only as a Stanford Working Paper, but has had a significant impact in the policy process. It has established Professor Wolak as an expert witness called on by both regulator and firms in the UK market, and these parties have regularly quoted from the conclusions of Wolak and Patrick (1997).
CHAPTER 3. MARKET POWER IN THE UK POOL

3.2.1 The Operation of The Pool

The level of demand for electricity varies stochastically throughout the day and seasonally, and supply, because electricity cannot easily be stored, varies correspondingly. Further, it is in the nature of electricity transmission and distribution that continuous 'electrical equilibrium' must be maintained. The organisation of electricity supply therefore, be it market driven, as in England and Wales, Norway, Argentina and increasingly, the USA, or centrally controlled, must respond to the challenge of matching supply to demand at every instant whilst minimising the avoidable social costs of doing so.

In the deregulated electricity market of England and Wales, the electricity spot market (or "Pool") is the mechanism designed to equate supply and demand at low cost. Generators compete to supply the market by submitting daily bids into the Pool, which acts as a 'clearing house.' All sales and purchases of electricity in England and Wales, with a few minor exceptions, occur via the Pool. The Pool itself is operated by the National Grid Corporation (NGC). Pool prices are determined by the offer prices, or bids, of generators, in conjunction with forecasts of demand. This information is used by the NGC to clear the market in every half hour, and payments to generators are in large part based on the bid price of the most expensive operating unit (the marginal plant). The Pool is closely approximated by a multi-unit uniform auction.\(^3\)

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\(^3\)I say only that the Pool is closely approximated by this model because the link between bids and production is not as straight-forward as in a uniform auction. The technical detail of electricity production, and in particular the necessity of maintaining network equilibrium in the face of transmission constraints, means that the dispatcher must check selected bids for "consistency" before allowing production. In this sense, electricity "auctions" are the first step on the continuum to "smart markets". The minute differences from the simple uniform procedure have been exploited to good effect by the generators, who use their
The Pool is virtually unlike any other market, since it must match supply and demand continuously to maintain network "electrical equilibrium", which requires that each generating unit follow the operation instructions of a central dispatcher. It therefore fulfills the function of simultaneously permitting generators to compete to supply the market, whilst allowing for overall coordination of generation and transmission. Competition in the England and Wales Pool is facilitated by generators submitting daily price and capacity bids which specify the minimum prices at which they are prepared to supply the stated amount of energy. On the basis of these "offer prices", a least-cost plan for generating units is drawn up for despatch, taking into account transmission costs and constraints. This "merit order" (or supply curve) of generating units, together with an instantaneous forecast of demand, determines which units will actually be asked to operate ("despatched") in any half-hour.

The Pool therefore determines electricity prices for each half-hour which reflect the changing balance between demand and supply over the day. As demand varies, different types of plant, with different economic and technical characteristics, are despatched at the margin to meet it. The short run marginal cost of electricity production - or system marginal price (SMP) - which is used to determine prices, varies correspondingly.

The Pool is thus a set of rules designed to allow competition in the sup-
knowledge of the despatch algorithm to optimise bids.

At one level of simplification, this makes the power market close to a textbook case, since there is a homogenous good sold by an (actual) auctioneer with no storage or inter-temporal substitution. However, as soon as one takes the details of "electrical equilibrium" into account, the textbook analogy starts to fail: locational and network congestion effects create pockets of market power that defy simple treatment.
ply of energy whilst also allowing for the overall coordination and control of generation and transmission. The mechanism by which prices are set is intended, *inter alia*, to ensure that the avoidable social cost of meeting electricity demand in every period is small. The Pool rules define an incentive mechanism which can allow, under appropriate circumstances, private profit maximisation incentives to lead to the maximisation of social benefit. In particular, the absence of "uneconomic" incentives elsewhere in the electricity supply chain is crucial to this end. The mechanism is operating correctly if and only if:

- each generator perceive that his profit maximising strategy is to bid plant at marginal private cost;
- marginal private cost is equal to marginal social cost.

The analysis of market power in the Pool as provided in the works of Green and Newbery (1992), Fehr and Harbord (1993), Anwar (1998) and Wolak and Patrick (1997) are accounts of the failure of the first of these. This chapter will emphasise the second in its explanation of one aspect of market failure in the England and Wales ESI, where this aspect is taken by Wolak and Patrick (1997) to be evidence of the first type of failure. I will argue in Section 3.3.4 is more properly seen to be explained by a wedge between private and social costs. The claim is that this wedge arises from a complex set of market failures in the gas market, and in the regulatory regime for electricity distributors, and not from any dominance in the market for generation.
3.2.2 Characteristics of Electricity Demand and Supply Technology

This subsection briefly outlines the way in which the engineering constraints of electricity production and the uses to which electricity is put combine to create "sub-markets" for electricity. The way electricity is consumed makes "peak-load pricing" models (for a thorough application to electricity markets, see Schweppe, Caramanis and Bohn (1988)) applicable. The technologies of generation allow for substitution between sunk and operating costs. All large-scale power systems use a mix of technologies corresponding (roughly) to the rate of use they can commercially justify. This technological characteristic of the industry is important in understanding the strategy that Wolak and Patrick (1997) argue is being employed.

As noted above, demand for electricity varies throughout the day. This means, in effect, that there is no single market for electricity, but rather a large number of temporally distinct markets. This is for two reasons:

1. the demand for electricity is derived from desires for given energy services at given times (the desire for boiling water at 7:30 am, or the need for motive power for the 9:00 am shift, for example). Most electricity consumers cannot easily or costlessly change the times at which they consume electricity, i.e. electricity demand is not easily substitutable across time;

2. electricity is expensive to store;

3. the varying capital intensity of different generating technologies mean
that a plant designed to supply power very infrequently will not be able to compete with a plant designed to supply power continuously. When a lot of power is needed, both types will operate; when only a small amount of power is needed, only the continuously operating type will be economic.

These factors combine to fragment the market for electricity into different markets at different times. Time dependent demand is common in other markets, although in less extreme forms. For example, a hotel room in a sea-side resort in summer is not easily substituted for the same room in winter. Of course, the prices of resort hotel rooms vary accordingly over time in an attempt to match supply and demand, just as they do for electricity. Whilst resorts might practice "peak", "mid-season" and "low-season" pricing, electricity prices vary every half hour, and in principle could vary continuously.⁵

3.2.3 Base-load, mid-merit and peak periods

There is not a single market for electricity but rather 17,520 markets per year. It is convenient nevertheless to follow the usual practice and aggregate those half hours with similar characteristics, and to consider them as a whole. That is, although there may be little demand substitutability between them, they are sufficiently similar to be analysed as a group.

⁵All but the largest consumers are shielded from this highly variable spot price by electricity retailers who bear the price risk by offering fixed price contracts. Electricity demand is relatively price insensitive—certainly in the short term—but highly sensitive to stochastic factors such as weather, the success of the national football team, the television schedule etc.
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Demand periods are commonly aggregated according to the type of generating plant that is called on to satisfy demand, which in turn is mainly a function of the level of demand relative to peak levels. A three-way classification is often used: base-load, mid-merit and peak generating capacity which are defined as follows:

**base-load** capacity is made up of plant that operates nearly continuously throughout the year, and that is almost never switched off;

**mid-merit** capacity operates for a total of between a third and half the year, and is switched on and off almost daily as demand varies;

**peak** capacity operates only very rarely, when demand is at or near its peak level - typically for under 500 half hours of the year, for just a few hours during the coldest winter days.

Each of these capacity types map onto types (or “tranches”) of demand periods, that can be aggregated into segments and analysed as if they formed a single market:

**base-load demand** is the market segment served exclusively by base-load capacity. These are comprised of moments when electricity demand is at its lowest (e.g. summer week-ends and non-cold nights). Demand in base-load periods is either comprised of “base-load customers” (e.g. three-shifting factories, some appliances in homes (storage water heaters, freezers . . . ), that consume power at a constant rate throughout the year), or of customers whose demand happens to occur when others typically do not consume (e.g. public street lighting, late night enter-
tainment, water companies). From the perspective of aggregating consumption periods into similar “types”, both “base-load” customers and “odd-patterned” customers make up the market for base-load power.

**mid-merit demand** is satisfied by base-load and mid-merit plant together. These periods are comprised of moments when most consumers are using electricity, but often not at their full consumption capacity. These periods are typically during week-days, when commercial and industrial consumption is high (near capacity), but domestic and recreational consumption is low.

**peak demand** is satisfied by base-load, mid-merit and peak capacity together. These periods are the ones in which demand is at, or near, its highest levels, which occurs as a combination of consumers using power at (or near) maximum consumption capacity, and of many consumers doing so simultaneously.

Each of the three market segments attracts distinctive technical and economic choices in supply. In particular generating technology imposes two trade-offs which to a large extent determine the “natural” supply technology in each aggregated market or market segment:

- a trade-off between the capital and operating costs of plant;
- a tradeoff between the operating cost and flexibility of plant.

Schematically, a relatively large capital outlay offers low operating cost and relatively inflexible plant. Coal plants for instance are expensive to build, cheap to run, and expensive to start and stop. Hence, if they are to
be run economically they must be operated without being turned on and off
too often i.e. they must produce large quantities of electricity by more or
less continuous running. This is to ensure that large capital costs are spread
over more units, and that operating costs do not become excessive. This is
achieved by running the plant as base-load plant. Gas plant, on the other
hand, can be very cheap to build but have historically been more expensive
to run. We will see below why this historical precedent failed to apply after
the period in the history of the England and Wales power market that has
come to be called “the Dash for Gas” (1991 to 1998).

3.3 How is Dominance Exercised? Patrick
and Wolak's Claims

Chapter 5 describes the work of Fehr and Harbord (1993) and Green and
Newbery (1991) on dominance in the England and Wales electricity supply
industry. Fehr and Harbord (1993) offer some summary graphs of bidding
behavior that are suggestively supportive of the equilibrium strategies they
describe. As noted in Chapter 5, Green and Newbery (1991) \textit{calibrate} their
simulation (and in particular the combination of demand elasticity and equi­
librium selection) to prices, and therefore do not in any sense offer evidence
of the abuse of market power. Wolak and Patrick (1997) construct a de­
tailed case that the two major players, National Power and PowerGen in
the England and Wales Pool exercise market power using a strategy that
Wolak and Patrick (1997) believe is closely related to the results of Fehr and
Harbord (1993). They describe the strategy, offer a reason for its (slightly counter-intuitive) plausibility, and offer evidence that it is used. I summarise the strategy and the reason suggested for its use, pointing out why it is counter-intuitive. I then suggest problems with the evidence offered in its favour. Given the difficulties of finding direct evidence of abuses of power in these markets, I conclude by suggesting that regulatory and competition policy might pragmatically try to use broad correlates of market power to guide policy.

3.3.1 Patrick and Wolak's Hypothesised Strategy

The strategy is thought to be the following:

1. In periods of high demand, when one of the major generators has "residual monopoly power", it restricts the quantity of base-load generating capacity offered, so that every part of the supply curve for power shifts inwards;

2. Such restrictions cause higher bid plant to set system price, thus increasing profits on those units that are sold;

3. The restrictions also reduce the reserve margin, which increases the probability of lost load (LoLP). The reserve margin measures the amount of capacity available before the system can no longer instantaneously equate supply and demand. The lower this quantity, the greater the chance that black-out ("loss of load") will occur. The intention in including such probability weighted black-out payments was that generators bids determine the day-ahead price, which is dependent on whether
black-out occurs or not. The day-ahead price is an expectation, with the Value of Lost Load (VLL) being the price if there is a black-out, and the uniform auction price being the price otherwise. The value of lost load related payments were instituted in the Pool as “loss of load probability payments”. The Wolak and Patrick strategy thus would have the effect of increasing loss of load probability payments.

4. This last effect is considered particularly important because of the increasing rate at which loss of load probability rises as the reserve margin falls. It is this effect that Wolak and Patrick refer to as “high powered”.

A generator is said to possess residual monopoly whenever some part of his capacity is essential to satisfying demand. In other words, if there is any amount of demand that no other supplier can supplier, then the generator can be said to be a monopolist over that unit. Fehr and Harbord (1993) show that in such circumstances, there is an equilibrium of the multi-unit uniform auction in which one bidder bids very high, and the other low enough not to be undercut. However, Wolak and Patrick (1997) do not claim that this is the strategy played. Figure 3.1 provides a pictorial representation of the strategy of item 1 above.

Item 3 above refers to the particular implementation of stochastic peak-load pricing that was adopted in the first version of the Pool. The Pool asks generators for bids 1 day ahead of production; thus, generators are paid the approximation to the actual spot price that can be made one day ahead; this approximation can be formulated as the price that would obtain if the market cleared times the probability that it clears plus the price that
Figure 3.1: Supply and demand curves for electricity are shown. One generator owns the plant represented with dotted lines on the "unmanipulated" (lower) supply curve. The instance shown is one of residual monopoly, since this generator knows that not all demand can be satisfied with others' plant. The Wolak and Patrick strategy is shown in the second, manipulated supply curve: the residual monopolist withdraws (in this case, all baseload) capacity from the market, but otherwise does not change his bids. The manipulated price is thus raised above the unmanipulated price, without any "lying" about trues costs on the part of the generator beyond the withdrawal of base-load capacity.
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would effectively ration the market times the probability that it does need rationing. The price that would ration the market is set by fiat at the Value of Lost Load, value of lost load = £200/MWh; the probability of rationing is determined by simulation and is called the Loss of Load Probability (LoLP).

Wolak and Patrick are right that the strategy shown in Figure 3.1 would increase loss of load probability, and therefore the component of price on which it depends. However, it is not clear at all that this would be a residual monopolist's preferred way of raising prices. This is the question to which we now turn.

3.3.2 Is the strategy an equilibrium?

Wolak and Patrick (1997) offer only a "word model" of the game being played. A summary of it is:

- Generators submit bid-schedules;
- The Pool determines payments, including loss of load probability payments;
- The regulator scrutinises behavior for abusive behaviour;
- The generators get punished for detected abuse.

The strategy of withdrawing base-load capacity in periods of high demand is prima facie implausible, because the generator pursuing it could have achieved identical prices by increasing his bids on higher cost plant. This strategy seems to dominate the Wolak and Patrick (1997) strategy because it
attains the same prices at lower cost to the residual monopolist, and therefore generates higher profits.

Wolak and Patrick (1997) defend their strategy on the grounds that the regulator is better at detecting abusive prices than abusive quantity strategies. The strategy thus depends on the regulator being bounded in a particular (and possibly odd) way. This view is developed into a formal model in Anwar (1998), where it is used to explore the virtues of a discriminatory auction. Anwar (1998) operationalises the restriction on strategies by insisting that a dominant generator can only offer his capacity at some multiple of its true operating costs.

Whatever the attractions of the formal properties of this formulation, it seems to me to be a poor characterisation of the regulator of the England and Wales electricity supply industry. The strategy, goes the argument, is "regulator friendly" but the strategy is underpinned by a naive regulator.®

### 3.3.3 Evidence for the Strategy's Use

Given the *prima facie* implausibility of the strategy, what are we to make of the evidence that Wolak and Patrick (1997) offer? They provide a number of observations that they claim are "consistent" with their hypothesis, and which taken together are intended to add up to the case. In this section, I argue that the evidence they offer can be interpreted in ways that are *not* consistent with the strategy. In particular, the inferences that they draw

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®There is some evidence that the then regulator was not naive. In a draft consultative document (Littlechild July 1997), he let down his guard momentarily by writing "in the present circumstances of market power of major generators...". He was usually more careful to make such statements hypothetical ("...were there to be generators with market power... ")
suggest a certain disregard for the institutional detail of the market. This, taken with the \textit{prima facie} implausibility of the hypothesised strategy, leads to the conclusion that a different sort of empirical strategy might be a better guide to policy.

Wolak and Patrick (1997) present evidence that:

1. price variability varies according to demand level;

2. base-load coal plant availability is lower in the England and Wales electricity supply industry than in the USA;

While we can see that these observations might be broadly consistent with the hypothesised strategy, I offer alternative explanations for the observations that respect the detail of the institutional constraints better than do Wolak and Patrick (1997). My alternative explanation of item 2 involves a lengthy discussion of the interplay of generator bids and long-term gas market contracts signed in the early 1990’s. I offer this lengthy explanation to illustrate the perils of staying too close to the measurable micro-data while ignoring the broader market context.

\textbf{Evidence of Dominance from Price Variability}

Wolak and Patrick (1997, Table 3) is presented as evidence of a special sort of price variability. Wolak and Patrick group the half hours in each year according to demand level. For each group, they compute the mean price, the standard deviation of prices, and the normalised standard deviation. In general, they find prices increasing with demand, and they find that normalised standard deviation first rises and then falls.
Wolak and Patrick argue that this “inverse-U” shape of price deviation against demand is support for their hypothesis: at low levels of demand, the market is competitive, so the outcome determinate; at high levels it is monopolistic, so the outcome is determinate; but at the intermediate levels,

...both Powergen and National Power attempt to not bid aggressively in terms of available capacity and bid functions, but the temptation of one to undercut the other makes it difficult to consistently maintain high values of System Marginal Price during these periods, because aggressive bidding by one of the two participants when the other bids high results in it being able to supply a substantial portion of the forecasted residual demand at this high price and leaving the market-price-setting higher bidding competitor with only a small fraction of the market. This desire to avoid being the substantially out-of-the-market price-setting generator brings about the observed high volatility in System Marginal Price (Wolak and Patrick 1997, page 36.)

One problem with using Table 3 as evidence for this logic is that generators are not free to alter offers for individual periods, but only for whole days in advance. Table 3 collects information for individual periods, whereas the logic outlined above will only ever apply to days. By grouping periods by demand level and inferring a common strategy, Wolak and Patrick make the error of assuming that each load level is sampled from a similar day. We know from the weather and season dependence of the most variable portions of power demand that this is tantamount to assuming constant weather and
light conditions throughout the year. The truth of the matter is that a given level of power demand may be the peak level for one summer day, but close to the lowest level for another winter day. Strategies are chosen for days at a time, so entire days must be analysed for any trace of strategic behavior.

In order to find support for the mechanism described, one would have to collect days by the frequency with which the three regimes occurred, and then compare means and standard deviations of prices across these day types. Wolak and Patrick (1997) quote Fehr and Harbord (1993) in support of their description of a mixed strategy at intermediate demand levels. However, Fehr and Harbord (1993) are explicit in the statement that their mixed strategy equilibrium derives entirely from the necessity to set a single bid for varying demand levels over the day ahead. A critical parameter for determining optimal bids in the model of Fehr and Harbord (1993) is the frequency with which demand is at "competitive" or "residually monopolistic" levels. Wolak and Patrick (1997) have not performed the right calculation to capture this effect.

One might think that they are in fact thinking of a different effect, possibly linked to the supposed "high power" of loss of load probability manipulations. If this is the case, however, Wolak and Patrick (1997) ignore an institutional detail which invalidates the measurement over single days, let alone half hours. In 1993 the regulator changed the rules for calculating loss of load probability x value of lost load payments in an attempt to stop the strategic manipulation of availability. The new mechanism took available capacity on each generating set as the maximum capacity of the previous eight days. Thus, a capacity withdrawal would only start to impact loss of
load probability if it had lasted eight full days. Hence, to examine whether volatility was being caused by availability declarations post 1993, one would want to group prices in “bins” relative to the size of the relevant residual demand (i.e. based on the “official” capacity figure).

Finally, the evidence of Table 3, whilst “consistent” with the Wolak and Patrick hypothesis, is also consistent with the hypothesis of a competitive market. The short-run supply curve for electricity tends to be a rather steep “S” shape (as shown in Figure 3.1). This means that at low levels of demand, small (possibly stochastic) shifts in demand or supply will not have a huge impact on price (supply is close to horizontal); similarly at very high levels of demand. However, small demand or supply shifts at intermediate levels of demand (on the upward section of the “S”) will lead to larger shifts in price, even in the absence of market power. Moreover, the way Wolak and Patrick select their data bins guarantees that they will be on the upward portion of the “S”. The lower portion is made up of base-load plant, whilst the upper portion is made up of peaking plant. Wolak and Patrick collect periods into those that either National Power or Powergen have residual monopoly over. But National Power and Powergen have most of their capacity in mid-merit plant. Therefore, National Power and Powergen will tend to be residual monopolists at mid-merit levels of demand, where the short-run supply curve for electricity is steep.

Overall, my contention is that Wolak and Patrick fail to build a sufficiently strong “unmanipulated” counterfactual to tell the difference, on the basis of Table 3, between a manipulated and a competitive market.
3.3.4 Dominance and Plant Availability

In Wolak and Patrick (1997, Table 4, page 58), USA and UK power plant utilisation rates are compared. The average utilisation rate of coal plant in the USA is found to be higher than that in the UK, whilst the utilisation rates of gas and nuclear plants in the USA tend to be lower than in the UK. National Power and Powergen are predominantly owners of coal plant, whilst their fringe competition to them predominantly uses the newer gas technology.

Wolak and Patrick collect availability data for different types of power stations in the USA, compare this to the availability of similar types of power stations in the UK and conclude that:

...The difference between actual average availabilities of gensets owned by National Power and Powergen versus Nuclear Electric and the IPPs is evidence consistent with the use of strategic withholding capacity by National Power and Powergen... (Wolak and Patrick 1997, page 43).

Availability and Utilisation

Wolak and Patrick (1997, Section 3.3) define availability as:

the percentage of each firm's annual potential generation capacity by fuel-type that is actually made available.

In much of the discussion that follows, availability shall be considered to be not significantly different from actual utilisation rate. This is not quite identical to the Wolak and Patrick (1997) definition, since a generating set can
be made available for production and yet not called on to produce. There are good reasons why this might happen: the National Grid Corporation needs to keep "spinning reserve" on the system, available instantaneously in case of emergency, but not needed otherwise; also, there have certainly been strategic incentives for generators to declare themselves willing and able to generate while knowing that a transmission constraint will prevent them ever having to do so.\(^7\) Both these types of effect will drive a wedge between availability and utilisation rates, tending to make availability higher in fact than when measured by \textit{ex post} utilisation. However, there are significant fixed costs to making power plant available, which will tend to reduce the gap. Moreover, the mechanism by which Wolak and Patrick (1997) believe availability is reduced applies just as strongly to \textit{ex post} utilisation. Therefore, framing the argument in terms of utilisation, as is done below, will lead to the same qualitative conclusions as would have been derived from an analysis of availabilities. The reason for dealing with \textit{ex post} utilisation is that the necessary data are more readily available.

Relatively low coal plant availability is adduced as evidence of the strategy by which the large players withhold base-load capacity. There are a number of difficulties with their evidence. The high UK availabilities of Independent Power Producer (IPP) Combined Cycle Gas Turbines (CCGTs) when compared to the USA is offered as evidence that the UK system, when

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\(^7\)Simulations showing this sort of effect are provided in Green (1998), and, for California's electricity supply industry in Borenstein, Bushnell and Stoft (1997). It strikes me that the real challenge facing decentralisation of power systems lies in the way in which the local monopolies that inevitably arise out of transmission constraints are incentified to behave efficiently. This question cannot bypass the much ignored question of the regulatory regime for transmission system investment.
in the hands of the competitive fringe, works as well as in the USA. The low availability of coal plant in the UK compared to the USA is adduced as evidence that the owners of coal (mainly National Power and Powergen) are withholding capacity.

However, it is argued in detail below that the high output of Independent Power Producers (because of odd contractual arrangements that have to do with Regional Electricity Companies' (RECs) market power) has led to coal's displacement in the UK from a traditional "base-load" market segment to a "mid-merit" market segment - instead of operating 80%-90% of hours, coal typically now operates 30%-50% of hours. Similar changes in market segment have not occurred in the USA. Hence, the low utilisation rates found by Wolak and Patrick (1997) are more obviously explained as the equilibrium outcome of a game between the gas suppliers, the Regional Electricity Companies and the regulator than a game between the regulator and the incumbent generators. I provide a "word model" account of these interactions below.

**Why has coal plant been so little used in the England and Wales electricity supply industry?**

The shift in utilisation rates of coal and gas plants in the England and Wales electricity supply industry is worth dwelling on. It is interpreted by Wolak and Patrick (1997) as a sign of dominance; it has also been acclaimed by politicians responsible for the environment as proof that "privatization is green"; all this with little understanding of the complicated interplay of un-competitive distortions between the gas and electricity markets that actually
caused the phenomenon. Two distinct questions are addressed:

1. Has the shift in utilisation been allocatively inefficient, as required for the argument of Wolak and Patrick (1997)?

2. What has caused the inefficiency—use of market power by the generators, or some other regulatory imperfection?

It is argued that the answer to question 1 is "Yes", and that the answer to question 2 is that other regulatory imperfections are the cause. The policy implications are very clear: if the regulator is concerned with these inefficiencies, then the Wolak and Patrick (1997) analysis leads to very different set of recommendations than the analysis presented here.

Since 1991, Combined Cycle Gas Turbine plant has increasingly been satisfying base-load demand periods, and coal plant has increasingly been used to supply the mid-merit segment. By the year 2000, approximately 17 gigawatts of new Combined Cycle Gas Turbine plant will have been added to the system (whose total capacity is currently 58 gigawatts).\(^8\) 14 gigawatts of new Combined Cycle Gas Turbine plant is currently operating or under construction. The National Grid Corporation estimates that the spate of new Combined Cycle Gas Turbine investment may lead the England and Wales market to having a "reserve plant margin" of up to 40% by the year 2000 compared to the 20% which the National Grid Corporation takes as "a notional margin...[based on international experience]...appropriate for discussion purposes".

\(^8\)This is taken from appendix 5.1 of MMC, National Power/Southern.
This very substantial investment in new Combined Cycle Gas Turbine has been widely discussed in energy policy circles and popularly referred to as the “dash for gas”. Newbery (Newbery 1995) has convincingly argued that this investment has largely been wasteful. It seems reasonable to argue that the exercise of market power by National Power and Powergen led to high profits in the industry, and therefore an inefficient level of entry by Combined Cycle Gas Turbine Independent Power Producers. However, Wolak and Patrick (1997)’s analysis is that the availability data is evidence of a particular type of equilibrium bidding; it has nothing to say about where the Combined Cycle Gas Turbine Independent Power Producer plant came from. It is not a primary aim of this paper to examine the arguments that the “dash for gas” was economically unjustified—the argument presented rests entirely on an assessment of how plant should operate once they are built, and hence on facts that can explain the changing pattern of utilisation rate between types of plant.

Since 1991, the new Combined Cycle Gas Turbine plant have increasingly been satisfying base-load demand periods, relegating coal to supplying the mid-merit segment. Table 3.1 shows total electricity generation by fuel-type between 1989 and 1995. It can be seen that the increase in Combined Cycle Gas Turbine output has been largely at the expense of coal.

Table 3.2 provides an estimate of the development of coal generation’s market share in the base-load segment. Whereas in 1990, coal had 29%
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<table>
<thead>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>76%</td>
<td>69%</td>
<td>62%</td>
<td>57%</td>
<td>49%</td>
<td>47%</td>
<td>45%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>23%</td>
<td>25%</td>
<td>27%</td>
<td>27%</td>
</tr>
<tr>
<td>Other Steam</td>
<td>0%</td>
<td>7%</td>
<td>12%</td>
<td>12%</td>
<td>8%</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Hydro</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>CCGT</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>7%</td>
<td>10%</td>
<td>13%</td>
</tr>
<tr>
<td>Imports</td>
<td>4%</td>
<td>4%</td>
<td>5%</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 3.1 shows that coal generation’s total market share has fallen by just under one half while Table 3.2 shows the base-load share falling by approximately two thirds. A large part of coal generation’s loss of market share can be explained by coal plant being forced out of the base-load market.

<table>
<thead>
<tr>
<th>Base-load Market</th>
<th>1990</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Capacity with load factor &gt; 70%, MW</td>
<td>3168</td>
<td>1210</td>
</tr>
<tr>
<td>As % of base-load market capacity</td>
<td>29%</td>
<td>11%</td>
</tr>
<tr>
<td>Approximate coal share of base-load output</td>
<td>27%</td>
<td>10%</td>
</tr>
<tr>
<td>Approximate Share of IPP CCGT output</td>
<td>0%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Table 3.2: Base-load Market Shares. The drop in the coal share of the base-load market is more than accounted for by the rise in the Combined Cycle Gas Turbine base-load market share. Source: MMC (1996) table 5.6, paras 5.80-5.90 & own calculations.

^Most baseload at this time is made up of Nuclear Electric’s plant, EdF imports and imports from Scotland.
Combined Cycle Gas Turbine bidding behavior and base-load market share.

As noted above, the type of capacity called on to operate in any half hour is determined in the England and Wales market by the offer prices for the marginal generating set. It is the bids of the Combined Cycle Gas Turbine plant relative to those of coal plant that therefore explain their rise in output and market share. Table 3.3 aggregates average bid data for 1995 prepared by the MMC. Observe that 77% of the Combined Cycle Gas Turbine capacity operating in 1995 was bid at 0 £/MWh, and 90% was bid below £7/MWh. The MMC (MMC 1996, page 124) comments on the disaggregated data, noting that:

"The nine IPPs fell into two groups. The first group included the eight gensets which bid zero for all incremental prices. The second group... had a low first incremental price, accounting for between 60 and 80 per cent of their output."\(^{11}\)

The implications of this bidding behaviour on Combined Cycle Gas Turbine operation depends on the bidding behaviour of all other plant, on the subsequent merit order, and on the levels of demand the National Grid Corporation must satisfy. The MMC’s estimates of average Independent Power Producer (i.e. that not owned by National Power or PowerGen) Combined Cycle Gas Turbine capacity during 1995 can be combined with their published estimates of output in 95/96 to indicate that the average load factor

\(^{11}\)"Incremental Prices" refer to generator’s freedom, under the Pool rules, to submit a bid schedule that is piece-wise linear. Each straight-line segment is referred to as an "incremental price".
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<table>
<thead>
<tr>
<th>Bid Range, £/MWh</th>
<th>MW of CCGT Bid</th>
<th>as % of new CCGT capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5848</td>
<td>77%</td>
</tr>
<tr>
<td>0.01-5.00</td>
<td>307</td>
<td>4%</td>
</tr>
<tr>
<td>5.01-7.00</td>
<td>668</td>
<td>9%</td>
</tr>
<tr>
<td>7.01-8.00</td>
<td>273</td>
<td>4%</td>
</tr>
<tr>
<td>8.01-9.00</td>
<td>284</td>
<td>4%</td>
</tr>
<tr>
<td>9.01-13.00</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;13.01</td>
<td>232</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 3.3: Average Combined Cycle Gas Turbine Bidding Behavior, 1995. Source: (MMC 1996) and own aggregation

for these plant was between 76% and 95%. The load factor of a plant is defined as Actual Output/Maximum Output, so an average load factor of between 76% and 95% indicates that the plant was only occasionally idle. In contrast, the same sources can be used to estimate average coal plant load factor, which is approximately 45%. In other words, Independent Power Producer Combined Cycle Gas Turbines run, on average, as base-load capacity, whilst coal plant runs at mid-merit.

This only partially confirms the strategy described by Wolak and Patrick (1997) and represented in Figure 3.1. In the example shown in the figure, base-load coal plant does not run at all in the mid-merit segment. Nevertheless, we can take these figures to be broadly in agreement with Wolak and Patrick (1997)'s table of comparative availabilities.

Combined Cycle Gas Turbine Costs and Bidding Behaviour—is base-load Combined Cycle Gas Turbine operation efficient?

The efficient operation of the Pool requires that generators bid in their plant at marginal private costs, and that marginal private costs equal marginal so-
cial costs. In this case, the efficient despatch of generation plant is achieved and hence the total social costs of electricity production are minimised. Allocatively efficient pricing of electricity can only occur if the marginal plant used to determine system marginal price is determined by a 'true' merit order—a merit order based upon the marginal social costs of generation for each plant type.

The purpose of this subsection is to argue that low bidding by Independent Power Producer Combined Cycle Gas Turbines is 

ex post rational, given the contractual structure they operate. Moreover, zero, or very low, bidding behaviour by the Independent Power Producer Combined Cycle Gas Turbines in the England and Wales Pool violates the conditions of efficient Pool operation, and hence distorts the operation of the electricity market. It is this distortion which Wolak and Patrick (1997) have measured in their comparative availability table, and not a distortion occasioned by the dominant play of the two large incumbent generators. All are agreed that price bids which do not reflect marginal social costs are likely to result in:

1. the inefficient despatch of generation units;

2. electricity prices which do not reflect marginal social costs.

The disagreement is in the analysis of the cause of these specific errant price bids.

---

12 A necessary and sufficient condition for efficiency will be somewhat weaker than the condition stated here: in both uniform and discriminatory auctions, there can be bids which do not matter from the perspective of efficiency, and bids in such cases do not need to be equal to private and social costs. “Truthful” bidding, although too strict, is nevertheless a sensible design goal, since it would be very difficult to conceive of implementing a scheme involving untruthful bidding only in those cases in which it did not matter.
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The marginal private costs of an Independent Power Producer Combined Cycle Gas Turbine are defined as the change in total private cost engendered by a small increase in output. When electricity generation increases, the major physical change in inputs is that more gas needs to be consumed. Thus the marginal costs of operation of a Combined Cycle Gas Turbine are largely determined by the costs of the additional gas which must be burned in order to produce an additional unit of output. These, in turn, are largely determined by the financial contracts which the Independent Power Producers have signed for gas supply with British Gas and the contracts for differences signed with the Regional Electricity Companies. These contracts are described in more detail in Section 3.3.4. Under their gas supply agreements with British Gas the Independent Power Producers typically have large quantities of gas contracted under long-term "take or pay" agreements; and are prohibited from the resale of the gas purchased under these agreements. Under their contracts for differences with the Regional Electricity Companies, the Independent Power Producer Combined Cycle Gas Turbines are completely insulated from Pool revenues. The effects of these contracts taken together is to make the private opportunity costs - or marginal costs - of gas for the Independent Power Producer Combined Cycle Gas Turbines zero or near zero.

The role of gas purchase contracts

Under their gas supply agreements with British Gas the Independent Power Producers:

1. have large quantities of gas contracted under long-term "take or pay"
agreements;

2. are prohibited from the resale of the gas purchased under these agreements.

The first condition means that, for large quantities of gas, whether or not the gas is consumed, the Independent Power Producer must pay for it. The second means that gas purchased by the Independent Power Producer can only be used to generate electricity from a specified site.

The variable or avoidable costs of running Combined Cycle Gas Turbine stations depends upon the nature of their gas purchase contracts. In order to recover their average gas purchase costs, Combined Cycle Gas Turbines should be bid into the Pool at prices greater than or equal to these costs. However, if gas is purchased under a take or pay contract then the short-run marginal, or avoidable, costs of Combined Cycle Gas Turbines depend upon:

1. the opportunity cost of gas in the electricity market, i.e. the value of holding gas to sell later into the Pool;

2. the potential for selling gas into the wholesale gas spot market.

The second of these is eliminated immediately in the “no resale” clause of the gas purchase contracts. The opportunity cost of the gas in the electricity market, however, depends on the quantity of gas purchased under “take or pay”: if the quantity is “large”, uneconomic bidding is likely to be frequent; if it is “small”, there may be no distortion. What counts as “large” or “small” quantities depends on the characteristics of the electricity system as a whole, and in particular on the prices of competing fuels. The Independent Power
Producer/Combined Cycle Gas Turbines have typically contracted for 75%-100% of output, which is almost certainly "large" in the sense required here. At the end of this section, evidence is provided to show that Independent Power Producer bidding behaviour is consistent with "large" "take or pay" obligations in this sense. We thus establish that the high utilisation of Independent Power Producer Combined Cycle Gas Turbine is due to contracting practices in the gas market, and that there are serious potential inefficiencies in the electricity industry associated with these. The reason why Independent Power Producer gas purchase contracts themselves contained such restrictive terms is likely to be linked to British Gas's dominance in the gas market at that time; but a full account would need to examine the negotiating positions of the Regional Electricity Companies. This would be an interesting area of further research for applied bargaining theory.

The Contracts for Differences

Independent Power Producers have signed long-term electricity sales contracts (Contracts for Differences, or CfDs) with the Regional Electricity Companies. These contracts effectively guarantee Independent Power Producers a price for their output which covers fuel and capital costs. One consequence is that Independent Power Producers are not affected by changes in the electricity Pool price, and that every unit generated contributes equally to revenues. However, the argument that the opportunity cost of gas under "take or pay" contracts is a function of the value of gas in the electricity market supposes that Independent Power Producer revenues depend on the price of electricity in the Pool.
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The Contracts for Differences isolate the Independent Power Producers' revenues from Pool prices, so make their operating decisions independent of Pool prices. Hence, whether “take or pay” gas contracts are for “large” or for “small” amounts of gas, the Independent Power Producer operators have no incentive to bid plant in an economic way.

Private Versus Social Costs

The marginal private costs of Independent Power Producer Combined Cycle Gas Turbine, at least for a large portion of output, is at or near zero. Thus, the uneconomic bidding Independent Power Producer Combined Cycle Gas Turbines may be consistent with the requirement for efficient market operation that bids are equal to marginal costs. However, efficient market operation also requires that marginal private costs equal marginal social cost. This is certainly violated by zero bidding. Here is an extreme example to make the point:

It can be seen from Table 3.3 that if demand were ever to be lower than 5848 megawatts in any half hour, System Marginal Price, on the basis of these bids, would be zero, whilst the marginal social cost of the electricity would still be positive. Marginal social costs must be positive in this example, because, at the very least, producing the electricity requires burning fuel which has a non-zero value elsewhere in the economy. Were demand to fall this low, not all gas would be consumed in those parts of the economy where it was most valued.

The social opportunity cost of each small increment of gas used in power generation can be taken to be the value of gas in alternative uses, and mea-
sured to a first degree of approximation by the gas spot market price. So a less extreme form of the argument above is:¹³

If there are any periods in which Combined Cycle Gas Turbine plant is contributing to satisfying electricity demand, and in which the gas used would have been more valuable in other parts of the economy, then Combined Cycle Gas Turbine plant is not being bid at marginal social cost. Thus, if Combined Cycle Gas Turbine plant is generating electricity and the gas spot price is higher than the System Marginal Price earned on gas use in electricity generation, then Combined Cycle Gas Turbine bids are contributing to a mis-allocation of resources.

Figure 3.2 examines Combined Cycle Gas Turbine costs and bids in 1995 in more detail. It shows the value that gas purchased in the spot market would have commanded had it been used to generate electricity. This starts in January 1995 at just above 10 £/MWh, and falls to 6 £/MWh by the end of the year (it is currently (mid-1996) back to its January 1995 levels, corresponding to 17 p/therm). In other words, this is an indication of the social opportunity cost of gas in power generation. If in any period gas was being used to generate electricity and System Marginal Price turned out below the value on the line, then the gas could more profitably have been sold in the gas market.

The last series shows an average (capacity weighted) of Independent Power Producer Combined Cycle Gas Turbine bids for the months in which

¹³The gas spot market price is only a rough indication of the value of gas in alternative uses because the gas market is itself a highly uncompetitive and manipulated market. The "market view" seems to be that British Gas likes to see (make) low prices at peak, when it is "short" and high prices in shoulder periods, when it is "long" in gas. This makes it difficult even to say whether the opportunity cost is above or below the spot price.
Opportunity Cost and Bidding Behaviour

Value of Spot Gas in Electricity Generation, £/MWh (assumes 47% efficiency)

- LT12 (16 p/therm)
- LT13 (21 p/therm)
- Average Capacity Weighted IPP CCGT bids

Figure 3.2: Combined Cycle Gas Turbine costs and bids in 1995. The two horizontal lines show the average fuel cost of electricity generated with gas bought under the Long Term Interruptible 2 and Long Term Interruptible 3 contracts with British Gas (BG). These contracts were the standard, published take or pay contracts offered by BG when the Independent Power Producer Combined Cycle Gas Turbines operating in 1995 were built. The lines show that if gas was being used to generate electricity in periods when System Marginal Price exceeded 10 £/MWh (Long Term Interruptible 2) or 13 £/MWh (Long Term Interruptible 3), then the gas consumed was recovering its average purchase cost through the Pool mechanism.
data is available. Bids are an offer to sell power at a specified price. From this series it is clear that Independent Power Producer Combined Cycle Gas Turbine plants have been offering to sell power:

- at a price lower than average avoidable cost (Long Term Interruptible 2 and Long Term Interruptible 3);
- at a price lower than the social opportunity cost of gas.

Averages of the type plotted in Figure 3.2 lose a great deal of information, particularly concerning the frequency with which Independent Power Producer Combined Cycle Gas Turbine plant operation has been economically sub-optimal, and thus an idea of the magnitude of the problem identified by Wolak and Patrick (1997).

Table 3.4 provides information not available from an examination of averages. It has not yet been shown that Independent Power Producer Combined Cycle Gas Turbines have actually been operating in any periods when the opportunity cost of the gas outside the power sector exceeds its value in the power sector—readily available average data do not permit an *a fortiori* argument to be constructed. Therefore, it might be argued that although the Independent Power Producer Combined Cycle Gas Turbine bidding provides the potential for economic distortion, it never occurs. The argument would be:

1. there are at least 6155 megawatts of Independent Power Producer Combined Cycle Gas Turbines that on average bid below marginal social cost (from Table 3.3);
Table 3.4: Combined Cycle Gas Turbine Bidding Frequencies. The first two lines give, for 1995, the number of hours during which System Marginal Price fell below 10 £/MWh and 13 £/MWh. These values are chosen as the Long Term Interruptible 2 and Long Term Interruptible 3 reference values. The next two lines show the load factor (which is the same measure as “average availability” in Wolak and Patrick (1997)) of a plant that operated only in periods when System Marginal Price exceeded these values. The last two lines provide a higher and a lower estimate of the average annual load factor achieved by the Independent Power Producer Combined Cycle Gas Turbines, gleaned from public sources (mainly MMC (1996)). The lower estimate is larger than the load factor implied by operating only when System Marginal Price exceeds the Long Term Interruptible 2 reference price, so we can conclude, a fortiori, that Independent Power Producer Combined Cycle Gas Turbines have been operating in periods when they cannot have been recovering their average fuel costs from the Pool.
2. but this plant would always anyway be operating, even if it did bid marginal social cost, so actual market shares are no different from what the optimum would have been;

3. this plant never sets System Marginal Price (this follows *ex hypothesi* from point 2), so electricity prices are never any different from what they would have been had bidding occurred at marginal social cost;

4. therefore there are no grounds for arguing that a distortion actually occurred.

The argument is flawed because it rests entirely on the unsupported and unlikely claim (in step 2) that the plant would always anyway have been operating, even if it had bid at social cost. Take, for example, April 1995, when the marginal social cost of gas (as measured by the spot market price) corresponded to an electricity price of 8.55 £/MWh, and when the capacity weighted average bid of the Independent Power Producer Combined Cycle Gas Turbines was 2.46 £/MWh. In this period, EDF’s highest tranche of capacity was bid at 6.4 £/MWh. Thus the Independent Power Producer Combined Cycle Gas Turbines were on average bidding below the EDF price, whilst the marginal social cost of the gas used was higher than the EDF price. The four periods in which the EDF set System Marginal Price at 6.46 £/MWh, therefore, should (on the basis of marginal social costs) have been periods in which System Marginal Price should have been at 8.55 £/MWh, and all these periods should have been periods in which EDF was supplying electricity and gas was being sold into the spot market. The Combined Cycle Gas Turbine bidding thus must have:
1. reduced EDF's revenues;

2. reduced French exports to the UK;

3. reduced the nuclear operator's revenues;

4. encouraged production from a socially sub-optimal fuel source.

Wolak and Patrick (1997) assert that the differences in utilisation between the UK and USA are evidence of abuse of market power and inefficiency. The arguments presented here have derived that the second of these is indeed the case, although it has taken considerably more effort than suggested by the simple comparison with USA utilisation rates. It will further be argued that this inefficiency is the result of a certain sort of market power, although not that suggested by Wolak and Patrick (1997).

3.3.5 Contractual Structure and Bidding Behaviour

It has been established that Independent Power Producer Combined Cycle Gas Turbine bids are typically below average fuel costs, and even below opportunity cost. This section describes the contractual incentives that have led to below cost bidding, and shows that these incentives imply that whatever happens to relative fuel costs, below cost bidding is likely to continue. In the face of such incentives, it is no great surprise that coal utilisation rates have fallen.

The view that the Independent Power Producer/Combined Cycle Gas Turbines have strong contractual incentives for their behaviour has been taken by a number of public bodies. For example, the Trade and Industry
Committee's First Report on British Energy Policy and the Market for Coal (January 1993) (HMSO 1993) noted that:

"Before privatisation, the merit order, which determined the order in which stations were called on to operate, was based on costs. Now it is based on prices bid into the Pool. The theory underlying the Pool is that generators will bid their marginal costs, i.e. the avoidable costs of operating in any particular half-hour. In practice, many stations are bid at lower prices to ensure that they run, usually because of provisions in contracts relating to the electricity supplied, such as EDF's contracts with Regional Electricity Companies and Independent Power Producers' contracts with gas producers requiring them to take minimum volumes. Thus coal-fired stations could, in theory, fail to be selected despite low costs..... The present operation of the Pool, combined with the contracts between Regional Electricity Companies and Independent Power Producers, does appear to disadvantage coal-fired generation...."

As another example, the MMC (MMC 1996) quote OFFER as defining "flexible" capacity as:

"... total capacity excluding nuclear plant and initial Independent Power Producers with take or pay contracts and the interconnector with France."

Implicit in this definition is a recognition that Independent Power Producer
Combined Cycle Gas Turbines can be considered a component part of “inflexible”, or base load, capacity because of their take or pay contracts.

The typical Independent Power Producer/Combined Cycle Gas Turbine contract brings together a plant operator (the Independent Power Producer), a buyer for the output (usually a Regional Electricity Company, who is usually a shareholder of the Independent Power Producer), and the gas supplier (usually British Gas, BG).

Gas Contracts

Prior to liberalisation, when British Gas was the monopoly purchaser and supplier of gas, almost all gas in the UK was sold by producers under long term “take or pay” contracts. Even after liberalisation, gas to gas competition was slow in developing, and the terms set by BG in its contracts can be taken to be the standard reference terms for the industry at that time. These contracts - often referred to as ‘depletion contracts’ - tended to be for the life of a gas field (15 to 25 years), and required that the gas purchaser take - or in any case pay for - a minimum quantity of gas per annum (the ‘minimum take or bill’), with limited opportunities for either varying the quantities taken within a year (the contract ‘swing’), or over the life of the contract (the ‘make-up bank’). The ‘minimum take’ in gas contracts were typically specified as a percentage of the annual contract quantity (ACQ), often ‘nominated’ by the seller, and range from 85% to 100% of this figure. At the contract’s expiry, the amount of ‘banked’ gas (i.e. the amount of gas below the ACQ not taken) was lost to the purchaser. The contracts are for consumption at a nominated premises, which excludes the possibility of
resale.

Table 3.5 shows an estimate of the Independent Power Producer Combined Cycle Gas Turbine capacity purchasing fuel under each type of contract. Although the BG contracts cover only 44% of capacity, it is reasonable to assume that the other contracts do not differ significantly in term or price - BG continued to be the dominant supplier, and therefore the “alternative of last resort” in any contract negotiation.

<table>
<thead>
<tr>
<th>Contract</th>
<th>MW</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Term Interruptible 3</td>
<td>1600</td>
<td>26%</td>
</tr>
<tr>
<td>Long Term Interruptible 2</td>
<td>1066</td>
<td>17%</td>
</tr>
<tr>
<td>Other</td>
<td>3462</td>
<td>56%</td>
</tr>
</tbody>
</table>

Table 3.5: Independent Power Producer Fuel Purchase Contracts. Source—PowerUk (1997) & own calculation

“Take or pay” is a slightly misleading name for these contracts; they are in fact “pay or pay” contracts - whatever the Independent Power Producer does, however much gas it consumes, it must pay 100% of the contracted quantity. Gas purchase costs are thus independent of operating decisions. They represent a fixed cost. Every unit of electricity sold generates added revenue, whilst incurring no change in costs (other operating costs are small). Hence, for quantities purchased under the “take or pay” rules, profit maximisation implies output maximisation.
Independent Power Producer Contracts with Regional Electricity Companies

The contracts for differences the Independent Power Producer hold with shareholder Regional Electricity Companies are financial instruments that relate Independent Power Producer operation to Regional Electricity Company payments and thus Independent Power Producer revenues. They differ in detail, but typically share the following characteristics:

1. they cover a period of 15 to 20 years;

2. they are signed between the Independent Power Producer and the shareholding Regional Electricity Companies;

3. all Independent Power Producer output is covered by the contract (i.e. the Independent Power Producer cannot sell power outside the contract terms);

4. payments are “netted out” from Pool revenue under either “net CfD” or “gross CfD” arrangements; in both cases, Independent Power Producer revenues are intended to cover costs, and are totally independent of Pool prices.

5. payments are made only when (and whenever) the Independent Power Producer is producing electricity (they are “non-firm Contracts for Differences”);

6. separate payments are made to cover capacity costs (usually based on plant availability) and variable costs (based on plant operation);
7. the pre-agreed process or formula for determining costs often ties costs to a “target efficiency” or a determinate fuel cost (e.g. the cost of Long Term Interruptible 3 gas) or both.

**Incentive Distortions due to the Contracts for Differences**

Characteristics 3, 4 and 5 lead to the clearest distortions in bidding incentives: 3 and 5 mean that all production is covered by a payment mechanism that, by characteristic 4, does not vary with Pool prices. Thus, if the Independent Power Producer wants to produce electricity on any given day, the safest strategy is to bid at or near zero (since this guarantees operation).

The importance of the distortionary impact of the Contracts for Differences will therefore depend on the frequency with which an Independent Power Producer wants to produce. This in turn will depend on several factors, amongst which the following are important:

1. The amount of gas contracted under “Take or Pay”. If this is large, there will often be periods when the Independent Power Producer wants to produce, to ensure that revenues under the CfD cover his fixed gas “Take or Pay” costs;

2. The unit profit that the Independent Power Producer can make under the terms of the CfD. If this is positive (for example because “target” efficiencies are exceeded, or because actual spot market fuel prices are lower than the price specified in the contract), then it will be earnt on every unit of output, whatever the level of Pool prices.

The Contracts for Differences re-enforce the incentives for the Indepen-
dent Power Producers to bid low because of their "Take or Pay" contracts. It has been shown that the opportunity cost of gas under "Take or Pay" is related to the expected value of the Pool price when operating. However, the Contracts for Differences break this link, and render the opportunity value of the gas dependent solely on whether or not a plant is operating. The Independent Power Producer is no longer concerned about when gas is consumed, only that it is consumed. Moreover, if unit profits are positive under the CfD, then the Independent Power Producer has an incentive to maximise output whether or not gas is under "Take or Pay".

The Independent Power Producer/Regional Electricity Company Contracts for Differences are different in nature from the sorts of futures contracts often used to distribute risk in large investments, and it cannot be argued that the contracts were necessary to the financing of these projects. Risk sharing contracts are common in the England and Wales Pool, since all the major producers (National Power, PowerGen, British Energy and EDF) have signed such agreements with Regional Electricity Companies. These traditional Contracts for Differences are pure financial hedging contracts, unrelated to any actual transactions in electricity, which means that they have no perverse influence on the operation of a competitive Pool. A typical example of a CfD is the following:

- a generator sells a CfD, which means that he has promised to pay the holder the difference between the actual Pool price and the "strike" (determined in the contract) price whenever the Pool price exceeds the strike price;
• the Regional Electricity Company buys the CfD and promises to pay the generator the difference between actual Pool price and the strike price whenever Pool price falls below the strike price.

In a competitive Pool, therefore, a generator’s payments under this CfD are not affected by his operating decisions— they are entirely a function of out-turn Pool prices. Nevertheless, the Contracts for Differences function effectively as risk-allocating tools because revenues and payments from the CfD are predictably correlated to movements in the Pool price (when the Pool price rises above the strike price, generator payments and Regional Electricity Company revenues increase). The Independent Power Producer/Regional Electricity Company contract payments, on the other hand, are entirely uncorrelated to Pool prices, so Independent Power Producer bidding cannot (except by chance) be economically efficient signals to the Pool operator.

**Regional Electricity Company Contracting Incentives**

The following argument is put forward by HMSO (1993) as one of the reasons for the supposition that the Regional Electricity Company investments in Combined Cycle Gas Turbines might be uneconomic:

All the Independent Power Producers have some equity participation by a Regional Electricity Company, and all have obtained funding on the security of long-term investments (usually 15 year) contracts to sell virtually all of their output to a Regional Electricity Company or Regional Electricity Companies. While their franchises exist Regional Electricity Companies are able to
pass on the costs of purchasing electricity to captive customers, whereas the return on their equity shares is unregulated. National Power suggests that Independent Power Producers 'provide a mechanism whereby profits can be transferred from regulated to unregulated businesses.'

This type of distortion should be settled by Regional Electricity Companies' regulatory obligation to purchase the cheapest available electricity. Whether Regional Electricity Companies' Independent Power Producer investments was compatible with this obligation was investigated by the electricity regulator OFFER in its 1992-93 Review of Economic Purchasing (Littlechild 1993). Although OFFER found that none of the Regional Electricity Companies had formally violated their licence condition to purchase electricity economically, OFFER's comparison of the Independent Power Producer contracts and the coal contracts with the major generators was incomplete.

In particular OFFER's comparisons of the Independent Power Producer-Combined Cycle Gas Turbine contracts with coal-based contracts was based upon price rather than cost comparisons; it did not consider the issue of the nature of difference contracts between Regional Electricity Companies and Independent Power Producers explicitly; and nor did it require that the Regional Electricity Companies contract via competitive tender.\(^\text{14}\) Indeed,

\(^{14}\)It is said, on the consultants' grapevine, that OFFER commissioned a study which did attempt a proper evaluation of the different types of contract using Markovitz (Markowitz 1991) portfolio evaluation models and techniques in use within the industry. This study apparently demonstrated that the Independent Power Producer Combined Cycle Gas Turbine contracts seemed rather expensive. The report was rejected by OFFER; the consultant dutifully agreed to redo the work with different assumptions.
OFFER stressed that the Regional Electricity Companies incentives for contracting with Combined Cycle Gas Turbines were as much based upon a desire to diversify away from National Power and PowerGen—the two major generators—as any desire to achieve lower prices, and this was in line with OFFER’s own desire for new entry, rather than regulation, to control the exercise of market power by the dominant generators. As the Director General himself wrote:

[The] Regional Electricity Companies have used equity stakes and long-term electricity purchase contracts to facilitate new entry into generation and to provide protection against the market power of the major generators....There is concern that some or all of the new Combined Cycle Gas Turbine plant may be more costly than the existing coal-fired plant which they displace, and that this may be due to in part to the over pricing of electricity from coal-fired plant” (OFFER, February 1993).(Littlechild 1993)

Hence even during the Review of Economic Purchasing it was recognised that that the Regional Electricity Companies motives for investing in, and contracting with, Combined Cycle Gas Turbines, were not simply to obtain electricity from the cheapest available source, and that their contracting strategies were partly based upon pre-existing market distortions. The analysis of Regional Electricity Company incentives under the Independent Power Producer contracts suggests that even if there had been no other distortions except the existence of a captive franchise market, Combined Cycle Gas Turbine investment would have made financial, if not economic, sense.
CHAPTER 3. MARKET POWER IN THE UK POOL

The Independent Power Producer contracts with the Regional Electricity Companies encourage zero bidding. The Independent Power Producer contracts with British Gas encourage zero bidding. In both cases, the incentives will not change if relative fuel prices change. Finally we can see that a proper account of the difference in average usage rates between USA and UK Combined Cycle Gas Turbines and coal plants does not support the Wolak and Patrick (1997) interpretation. It is not that coal plant is withdrawn from the market to increase prices, but rather that Combined Cycle Gas Turbine plant is built under contracts that allow Regional Electricity Companies to exploit their captive customer base, and British Gas to exploit its upstream gas market power.

3.4 Empirics to guide regulatory action

Wolak and Patrick (1997) only ever say that their evidence is "consistent with" the hypothesised strategy. I do not think this is obviously wrong, but I hope to have suggested that other interpretations are equally consistent with their evidence, and more plausible given the wider context of the England and Wales electricity supply industry. The extended critique of Wolak and Patrick (1997) points to a more general problem: in markets where strategies can be extremely involved and hard to identify, how can empirical work be put to best policy use? I have no answers, but point to one direction for future research.

A regulator under a complex mechanism is forever running to keep pace with the inventive strategies of his charge. The regulator does have teeth
that are frightening to dominant firms, like the power to engage anti-trust proceedings, to impose price caps etc. However, the dominant firms are forever pushing at the limits of the acceptable, always ready to back down from a strategy that will lead to all-out confrontation. In some stage of this war, no doubt, the firms adopted a strategy close to that described by Wolak and Patrick (1997). The regulator closed the immediate mechanism of this abuse relatively early. This has simply pushed the war further “underground” into the labyrinthine detail of repeated strategies, to strategies playing off the interactions of spot and contract markets, and to strategies designed to exploit the computational quirks of the dispatch algorithms. Under such circumstances, to attempt to limit market power by plugging every gap as it appears is like plugging a leak only to find water seeping through from elsewhere.

If market power is exercised in ever-more inventive ways through the detail of the market, it will always be difficult for the outside observer to uncover. What we need is phenomena that are general correlates of market power, irrespective of the means of their administration. The most obvious of these is profit. However, there are some difficulties: the England and

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15News Corporation is playing this aggressive game with regards to sports broadcasting rights in the UK. The Monopolies and Mergers Commission ruled that News Corporation’s takeover bid for Manchester United football club would be likely to lead to News Corporation’s dominance in the market for television rights on football matches. The argument the regulator accepted was that ownership of the largest football club would give a broadcaster a “toehold” (Bulow, Huang and Klemperer 1999) in any auction for broadcasting rights. The regulatory victory, however, has been short-lived: News Corporation is now following a strategy of buying small percentages of many clubs, tied to contracts which allow News Corporation to negotiate media deals on the club’s behalf. The impact will still be the acquisition of a toehold to be exploited in the market for television rights on football matches, and one which the current competition legislation would find difficult to challenge pre-emptively.
Wales Pool is not the only market in which the major players are involved; principal-agent difficulties can lead managers to exercise market power in non-profit generating ways; and so on.

A possible general correlate is the liquidity of derivative markets around the manipulated spot market. Gas and electricity futures are very thinly traded in the UK, with almost no non-physical traders involved. Commentators loosely relate derivative market “thinness” to manipulation in the price of the underlying asset. Some models of this readily spring to mind—for example a moral hazard model in which dominant players sell insurance in the form of Contracts for Differences, and only restrain their price-manipulating behavior if they have sold enough. Much more work needs to be done to explore the strategies available and their links to liquidity. The intuition remains: competitive spot gas and electricity prices might be expected to have attractive portfolio characteristics, and yet we find that these assets are not commonly used for portfolio management. Good theoretical accounts of the ways market manipulation destroy the attractions of derivative markets could become a useful guide to competition policy and a good yardstick of regulatory success.
Chapter 4

Uniform or Discriminatory?
The case of the UK gas storage market

4.1 Multi-Unit Uniform and Discriminatory Auctions: Background and Hypotheses

In a multi-unit auction, each player can bid a separate price for each unit being sold. In uniform and discriminatory multi-unit auctions with $n$ goods for sale, each bidder receives as many units of the good as she has bid prices in the top $n$ of all bid prices. In a multi-unit discriminatory auction, a bidder pays the bid she made for each unit she receives. In a multi-unit uniform auction, all bidders pay the same price for units received, and the price is determined as being either the value of the lowest successful bid or of the
CHAPTER 4. UNIFORM OR DISCRIMINATORY IN UK GAS?

The highest unsuccessful bid.\(^1\)

Figure 4.1 provides a pictorial explanation. There are four units on sale, and two bidders submit bids. These bids are aggregated by ordering them from the highest bid to the lowest, as shown in the bottom graph. The number of units allocated is identical in the uniform and discriminatory auctions: it depends only on the ordering of the bids, not on the payment rule. The uniform and discriminatory auctions imply different payments from the bidders. The bidders therefore face very different incentives in the two auction formats, which will therefore invite different bidding behaviour. This chapter investigates behaviour under the two auction forms in the context of a design for the UK gas storage market.

\begin{itemize}
  \item \textbf{Price} \quad \textbf{Bidder 1 bids:} \quad \textbf{Bidder 2 bids:}
  \item \textbf{Quantity} \quad 1 \quad 2 \quad 3 \quad 1 \quad 2 \quad 3
  \item \textbf{Aggregated bids} \quad 4 \quad 3 \quad 2 \quad 1
  \item \textbf{Supply} = 4
  \item \textbf{Allocations} \quad \textbf{Bidder 1 is allocated 2 units}
  \textbf{Bidder 2 is allocated 2 units}
  \item \textbf{Uniform Price} \quad \textbf{Value of lowest accepted bid} = 2
  \textbf{Value of highest rejected bid} = 2
  \textbf{Uniform price} = 2
  \item \textbf{Payments} \quad \textbf{Bidder 1 pays:}
  \textbf{4x1 + 3x1 = 7 in a discriminatory auction}
  \textbf{2x2 = 4 in a uniform auction}
  \textbf{Bidder 2 pays:}
  \textbf{3x1 + 2x1 = 5 in a discriminatory auction}
  \textbf{2x2 = 4 in a uniform auction}
\end{itemize}

Figure 4.1: Allocations and payments in uniform and discriminatory auctions.

The history of the debate over the suitability of uniform (also known as “market clearing price”, or even “competitive”) against discriminatory (or

\(^1\)Ties are resolved in various ways: randomly (the economic theorist’s typically preferred method), or by allowing re-bids to break ties (often bidders’ preferred solution).
"pay-your-bid") multi-unit auctions is long. It is recounted in Binmore and Swiezbinski (2000). US Bond auctions were traditionally sold on a discriminatory basis; Milton Friedman (incorrectly) argued that a uniform auction, being the proper generalisation of the single unit, English (ascending) auction, would be preferable. It was thought that the dominant strategy of bidding your true valuation would extend to the multi-unit uniform. According to Smith (1991) (page 510), Friedman argued both that the auction outcome would be more closely competitive and that it would produce more revenue than the discriminatory. The US treasury performed some experiments which “suggested the conclusion that Treasury revenue was increased by the competitive [i.e. uniform] treatment”, although not sufficiently for the Treasury to swap formats permanently.\(^2\)

Kagel and Levi (1998) provide a very careful experimental analysis of sealed-bid and open-outcry uniform auctions, as well as some results on Vickrey and Ausubel procedures. Their experiments show the theoretically predicted “shading” inefficiencies of the uniform.\(^3\) The experiments of Kagel and Levi (1998) are designed in a very different mode from the experiments described below. They try to construct the minimal environment in which the theoretically explored inefficiencies can arise. This has the virtue of eliminat-

\(^2\)The interpretation that revenues increased because of the change of format is surprising, both in light of auction theory (see Binmore and Swiezbinski (2000)), and in the light of our experimental results reported here. It should be noted that the result of this field trial is also consistent with the hypothesis that the participants in these auctions had settled on a repeated game, "collectively dominant", equilibrium, which was disturbed by the introduction of a new form—any new form would have done.

\(^3\)"Shading" is used in the auction literature to refer to bidder behaviour in which bids are offered which differ from true valuations. The image of "shading" is probably most apt for a discriminatory auction, in which a bidder is tempted at every turn to take a "shade" off every bid. Chapter 2 described the odd case of an auction in which rational shading sometimes implies an exaggeration of valuation—a bid inflation, rather than shading.
ing confounding causes, and allowing a practicable case-by-case identification of "shadings". The experiments described here, on the other hand, are attempts to recreate a realistic auction setting. Thus, we can think of the method of Kagel and Levi (1998) as being aimed at testing a theory, whereas this is aimed at testing a design.

Binmore and Swiezbinski (2000) conclude their survey with the view that:

\[\ldots\] time and budget constraints often limit the complexity of laboratory experiments. In [previous] experiments important features of real world auctions were not included \ldots all subjects have the same information about the value of the commodities to be auctioned. Nor could subjects trade claims to the auctioned items amongst themselves. Yet it is commonly believed that asymmetries in information and the presence of [resale] markets are crucially important in determining outcomes \ldots The case for running both laboratory experiments with real subjects and computer simulations with programmed "smart agents" in more realistic environments is very strong.

The experiment described in this chapter includes asymmetric information, and, for one treatment, resale markets. They are a step in the direction suggested by Binmore and Swiezbinski (2000) of increasing realism in apparently relevant directions. The further suggestion that similar models be simulated by "smart agents" is hoped to be a future direction of this work.
CHAPTER 4. UNIFORM OR DISCRIMINATORY IN UK GAS?

4.1.1 Historical Background to the British Gas Storage (BGS) Auctions

The uniform versus discriminatory debate has been active in UK energy regulation. A uniform auction was in use for 10 years in the UK electricity pool (see Chapters 3 and 5). In this context, it was criticised by Fehr and Harbord (1993) as being an inappropriate generalisation of the single unit Vickrey, and of giving rise to perverse "shading" incentives. A similar point about shading and inefficiency is made in Green and Newbery (1991). The gas regulator argued consistently for a uniform auction for gas storage capacity, an argument which was resisted on theoretical grounds by Binmore and Curzon Price (1998) and by the owner of the capacity, British Gas Storage (BGS) because it feared the revenue consequences of the proposed format.

British Gas Storage (BGS), the owner of the storage facility in the UK, had a strong business intuition that a discriminatory auction would be better for its revenues. Binmore and Curzon Price (1998) alluded to theoretical reasons for believing that a uniform auction would eventually lead to low revenues and inefficiency, just as it is claimed to have led to high prices (and possibly inefficiency) in the UK electricity pool by authors such as Fehr and Harbord (1993), Green and Newbery (1991), Wolak and Patrick (1997), and Anwar (1998).

The regulated firms in UK energy markets have also actively debated the desirability of allocating goods by auction at all. Appendix A.1 considers the question of how much "useful allocative work" is done by the auction mechanism as against the participants. This analysis, in the style of Gode and Sunder (1993), suggests that, for the context considered here, a significant amount of effort is supplied by the participants rather than the mechanism.

The "Revenue Maximising Auction", analysed in Chapter 2, was proposed by the regulator at one point in the negotiation process.
The regulatory negotiation allowed BGS to stick with the discriminatory format. A first discriminatory auction was run under both experimental and "live" conditions. The academic interest of the exercise was limited, since no proper controls were included.®

A year after these experiments, in November 1999, BGS was to run another set of live auctions and was prepared to renegotiate mechanism details with the regulator. BGS therefore asked ELSE® to perform a more satisfactory test of the uniform versus discriminatory format in order to inform its negotiations with the regulator. BGS was primarily interested in examining the relative revenue performance of the two in order to determine its own objective interest; it was nevertheless also interested in knowing the efficiency properties of the two forms in order to understand the regulator's objective interest.

ELSE assessed BGS' request in the light of the previous limited experiment and of theoretical predictions, and suggested a design which would test the aggregate properties of uniform and discriminatory auctions while varying two environmental variables which we expected might be significant: the elasticity of bidders' valuations and the presence or absence of a resale market.

The reason for picking the elasticity variable as a variation arose from our lack of firm information about the actual price elasticity of valuation in the

®The main purpose of the experiment was to perform an additional check that none of the extraneous institutional detail bolted on to the finally agreed mechanism produced perverse incentives. In particular, a slightly complex pre-emption mechanism caused some worry. The design thus had a very limited and narrow goal.

®ELSE is the Economic and Social Research Council Centre for Economic Learning and Social Evolution, headquartered at University College London.
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The main concern was the robustness of any ranking of auction choices to the elasticity. The theoretical models of uniform and discriminatory auctions are largely silent on the impact of elasticity on outcomes, while casual observation in a precursor experiment suggested to us that elasticity might be significant.

The reason for picking the "secondary market" condition was that a relatively new and still illiquid secondary market in gas derivatives was gaining momentum and Enron, at that time the major trader in that market, was already offering customers "virtual storage" contracts: financial instruments that mimicked the revenue flows available from ownership of storage capacity. There was genuine uncertainty about how "deep" the secondary market would become. Industry perception was that the secondary market would not be as attractive to major players as the primary market, but would nevertheless provide some substitute to auction purchases. In a design choice that emphasises representational realism rather than pure theoretical interest, an "exogenously unattractive" secondary market was simulated.

4.1.2 Prior Expectations

The eight conditions tested are tabulated in Table 4.1, with conditions listed A to H.

The previous limited experiment and theoretical results led us to a certain number of prior expectations. These are described here.

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8The operation of the secondary market, and the relation of this model to the "Private Value" (PV) and "Common Value" (CV) model of the auction, is elaborated in Appendix C.
Discriminatory auctions would generate higher revenues than uniform auctions

We know that there exist many low revenue equilibria of the uniform auction for which revenues are below the perfectly competitive level—Ausubel and Cramton (1998) and Binmore and Swiezbinski (2000) provide the theoretical background for this effect. The multi-unit discriminatory auction is relatively under-studied, especially in conditions of asymmetric information and risk-aversion by the bidders. In a precursor set of BGS experiments, in which we only ran discriminatory auctions, revenues were systematically above the perfectly competitive level.

Thus, the theoretical observation and previous experimental evidence led us to predict higher revenues in the discriminatory than in the uniform auction. This expectation was confirmed for the condition without a secondary market, although not for the case with a secondary market.

Ambiguous effects of Elasticity We had ambiguous expectations for elasticity comparisons. The standard theory of uniform auctions, as presented in Ausubel and Cramton (1998) and Binmore and Swiezbinski (2000) is more or less silent on the question of the effect of elasticity, since these analyses demonstrate a multiplicity of equilibria, with all al-

<table>
<thead>
<tr>
<th>Conditions</th>
<th>No Secondary Market</th>
<th>With Secondary Market</th>
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<tbody>
<tr>
<td>Uniform</td>
<td>Inelastic</td>
<td>Elastic</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Discriminatory</td>
<td>D</td>
<td>F</td>
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Table 4.1: Conditions for uniform/discriminatory experiments.
locations and prices below the competitive being supported, regardless of the elasticity of the bidders' valuations.

However, conversation with subjects of the limited precursor experiment suggested that the elasticity of the bid functions of other players might play an important role in determining the amount of shading. In particular, players in the pilot were shown very elastic aggregate bid functions for the other players, offering some but very little positive feedback from shading. Several participants noted that they understood, on seeing the very flat aggregate "other players" bid curve, that shading in a discriminatory auction was risky and did not yield high benefits.

If all other players have elastic bids, then a small shading of my bid will, *ceteris paribus*, bring me only a small price reduction and may lose me substantial surplus. Hence, if there is any reason to believe that the elasticities of bid functions are related to the elasticities of valuation functions, we would expect less shading in elastic than in inelastic treatments. (The effects related to the elasticity of others' bid functions is referred to below as the "strategic" effect of elasticity.)

However, there is another effect of elasticity. The risk to a player of marginally increasing her shading is that she ends up losing a unit on which she would have earned some surplus, all because of her "greedy" shading. The marginal surplus at risk will be greater for an inelastic

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9This would be a similar to the assumption of "k truthfulness", whereby agents are modeled as submitting bids which are always translations of their true value functions, in Berhmeim and Whinston (1986). See discussion in Chapter 2.
own-valuation curve than for an elastic valuation curve. A risk-averse bidder would therefore be expected to shade more under elastic valuation than under inelastic valuation. (This is referred to below as the “surplus at risk” effect of elasticity).

The experimental results broadly confirmed the ambiguous elasticity impact.

The secondary market should induce more shading in the primary auction

Appendix C argues that the secondary market should be construed as having two effects:

1. Providing a competing forum for subjects’ sourcing of gas storage;

2. Adding a common value (CV) component to subjects’ primary auction valuation curves;

In the first case, to the extent that the secondary market is an attractive substitute to the auction, we would expect increased shading in the auction as bidders shift demand out of the auction and into the secondary market. In the second case, we would expect a decoupling of primary auction bids from primary auction valuations. Subjects’ bid-level shading behaviour was analysed to test these hypotheses. On balance, the evidence suggests that hypothesis 1 dominated bidder behaviour in these experiments.

Learning Effects We would expect bidders to refine their bidding strat-

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10Cox, Smith and James (1984) perform experiments on multi-unit uniform and discriminatory formats under the assumption of perfectly elastic valuation curves for each bidder, and so do not consider the effect of elasticity.
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egy as the sequence of auctions progressed. This was suggested in the previous, limited series of experiments, in which bidders in a discriminatory auction gradually increased the shading of their bids. However, the experimental design—again a limitation—did not involve the sort of "switch treatment" recommended—for example in Coppinger, Smith and Titus (1980)—to test for path-dependent effects like learning. The learning hypothesis was therefore tested in these experiments less directly by looking for statistical differences between early and later sequences of bids.

4.2 Multi-Unit Uniform and Discriminatory Auctions: Experimental Design

Table 4.2 shows the sequence of treatments. Each experimental session consisted of 10 auctions without a secondary market followed by 10 auctions with a secondary market, which allowed for the possibility of post-auction trading. 4 sessions of 10 auctions were performed for each of the discriminatory cases (high and low elasticity) and for the uniform low elasticity case. 5 sessions of 10 auctions were performed for the uniform high elasticity case, although in two cases—30-11-99 and 11-11-99—the data for the secondary market condition was lost due to software problems.

The experiments were performed in the ELSE laboratory in the psychology department of University College London between November 6 1999 and December 15 1999. Students were recruited from the postgraduate e-mailing
list and earned an average of £25.70, with £7.50 as a turn-up fee, and the remainder performance related. Participants were told that they could lose up to £2.50 of their turn-up fee through bad play.

### 4.2.1 Experimental Design and Design caveats

#### Effects of Repetition

The experiments make use of repeated auctions in the hope of studying behaviour in particular auctions. There is a built-in modeling assumption that repeated-game effects will not be significant enough to invalidate the methodology. It is hard to test the validity of the assumption, because behaviour in repeated games can be conditioned in such a wide a variety of ways on past
behaviour. Moreover, some repetition is necessary simply to allow participants the time to learn about the strategic environment. Appendix A.1, in the context of “zero intelligence” benchmarks of auction performance, makes some reference to apparently unreasonable behaviour, such as bidding outside the value curve. It was found that 8% of all bids in the no secondary market discriminatory auction and 24% of all bids in the no secondary market uniform auction violated the one-shot budget constraint, while none violated the overall experiment budget constraint. The measure of violations was simply to count the number of bid-points lying outside any point on the value curve divided by the total number of bid points. It is a rough measure in that it does not take into account the gravity in terms of effect on pay-off of any violation. The high number of uniform auction violations may reflect the fact that many bids have no direct payoff consequences at all in a uniform auction. The high frequency of violations may therefore exaggerate the extent of “odd” behaviour. 11

Whatever the reason for this behaviour, it certainly cautions against unguardedly taking the results of single auctions or experiments to reflect general truths about one-shot outcomes. The statistical analysis below makes a rough distinction between an early learning phase and later phases. However, it should be recognised that this does not address the whole problem of controlling for repetition. A useful future experiment would run a series of sessions with varying numbers of repetitions, and varying the type of repetition with a switching treatment, in order to determine the significance of

11 Appendix A.1 looks more closely at the violation of one-shot budget constraints and its relevance to the measurement of the amount of “economic work” performed by the subjects and the auction.
repeated effects in settings of this sort.

Lack of Switch Treatments

The experimental design did not involve any "switch treatment", as, for example, recommended in Coppinger et al. (1980). A "switching treatment" involves alternating the conditions: having groups of subjects, for example, performing both uniform and discriminatory auctions, and also having conditions cycle, so that subjects might return to an auction without secondary market having been subjected to the secondary market condition. The advantage of switching treatment designs is that they are more informative—by returning to previous conditions, they allow one to test directly for learning and other history-dependent effects. Although the design without switching treatment does allow some testing for learning effects, and although repetition allows for increased confidence that results are not due to sampling variation, a switching treatment would have been preferable in statistical terms.

Design Choices

Auction Type Discriminatory and uniform price auctions were conducted.

Participants There were five participants in each auction. One of these larger than the other four. The larger firm’s valuation curve lies everywhere above the valuation curves of the four others. This structure was chosen to reflect the strategic realities of the UK gas market, where British Gas Trading (BGT) accounts for approximately half of
all trades. A small number of oil majors (Shell, BP, Texaco and Elf) together account for about 30% of trades, and a large number of small “noise” traders account for the rest. The noise traders were excluded from the auction, but “included” in the secondary market as automatic traders. This modelling choice was made for convenience, and any re-run of the experiments would try to model the noise traders consistently in both markets.

**Elasticities** Experiments were conducted with either high or low elasticity bidders. Eight In eight of the seventeen experiments, all participants were low elasticity, and in the remaining experiments, the value curves were high elasticity”. Typical value curves are shown in Figure 4.2.13

**Uncertainty** Subjects were provided with visual representations of the range of other subjects’ valuation curves before each round of bidding. Five possible value curves were shown for each other bidder. Among the five was always to be found the true value curve, but there was no way of telling which the true curve was for sure. The true value curve changed from round to round. This information was presented visually to give the bidder a sense of the envelope of possibilities he faced. The subject’s own value curve was shown to her and known for sure.

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12 The precursor experiment contained 9 subjects, with 4 “small” traders as well as these above. We faced problem of keeping “small” traders, who had very little individual influence on outcomes, interested in the game. Simply scaling monetary pay-offs did not seem to be an adequate response.

13 A large number of value curves were generated: one for each round, representing the real value curve known to the bidder; a further five per round per bidder were generated in order to make the “possible” aggregate curves that the other bidders saw, as described under “Uncertainty”, page 118.
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Figure 4.2: Example Value Curves for the Bidder Types

It is unlikely that firms in the gas market would in fact be certain about their own value curves, since the valuation derives from such a large number of parameters, themselves uncertain. Firms in the industry use scenario analysis to capture a range of valuations, and future experiments could usefully explore the impact on actions and outcomes of uncertainty in own-outcomes.

Sequence Subjects participated in ten rounds with a secondary market and ten rounds without. Bidders had five training rounds in which they played without a secondary market. When it came to “real” play, bidders were told that the structure of the game would be fixed for ten rounds, and that they would play 20 rounds in all. They were not told at the start how the secondary market condition was to operate. An inconvenience of these long sequences of repeated play is that they allow bidders the opportunity to experiment with repeated game strategies.
Future work could usefully try to replicate the results obtained here but with a large pool of subjects each interacting in “blind” random groups.

Secondary Market In rounds eleven to twenty, subjects participated in a secondary market after the auction in which re-trading could occur. The secondary market was modeled as a competitive, almost frictionless market, and trading was automated by the experimental software. Appendix C provides an extended description of the treatment of the secondary market.

In the secondary market condition, players first bid in the auction, and were shown allocations and profits just as in the condition without a secondary market. Any amounts purchased in the auction would, in the second phase, contribute to the secondary market aggregate gas supply. Some “small” (up to 5% of volume) “noise” supply was also added to aggregate supply in the secondary market. Aggregate demand was made up of the aggregate valuation of the auction participants, plus some small (up to 5% of volume) “noise” demand. Once aggregate supplies and demands had been (automatically) constructed, the experimental software determined efficient allocations for each player and performed trades at the uniform, market clearing price. The automatic handling of the secondary market ensured that the market could be cleared speedily; the method also implied that only profitable trades occurred: it was impossible for a subject to lose money through sec-
secondary market participation. The secondary market should thus be viewed as a forum providing a “fair second chance” to traders in the primary auction. It was not intended to reproduce the characteristics of perfectly competitive secondary markets which generate pure Common Value frameworks in auctions. Appendix C, Section C.1.2 provides and extended discussion of this point.

Information Feedback At the end of each round, each subject received the following feedback: (1) the own firm’s profit without and with secondary market, (2) the auction price, (3) the own firm’s allocation before and after secondary market trading, and (4) some information about the aggregate of the other firms’ bidding curves. This information consisted of 5 possible curves, one of them being the actual sum of the other firms’ bidding curves. Under this scheme, the subjects could infer, with some degree of confidence, how well they could have done, had only their own bids changed.

It is difficult to judge how much such information to provide. On the one hand, providing perfectly accurate “counterfactual” information is unrealistic and one might expect would pre-dispose subjects to certain types of adjustment in behaviour. In particular, if you know exactly how well you could have done under a different bid, it seems plausible that ameliorating, “better response” behaviour is being encouraged.

The overall effect of the secondary market can be thought of as “undoing” any inefficiencies in the auction allocation, and rewarding subjects for the trades by paying sellers and charging buyers the uniform market clearing price.

It would be interesting to extend this experimental work in the direction of testing such effects. Conditions with different amounts of counterfactual information would be tested for a bias towards ameliorating behaviour.
On the other hand, to provide too little is to give subjects a very hard task in terms of trying to understand the strategic nature of the interactions.

4.3 Experimental Results

4.3.1 Description of the Data

For each auction conducted, seller revenue and efficiency measures were constructed. Seller revenues are taken to be the sum of all amounts paid by the subjects (in the example in Figure 4.1, revenues are 12 in the discriminatory auction and 8 in the uniform auction). This measure is normalised by computing the total payments which would have been made under a uniform price in a perfectly competitive market, and expressing out-turn revenues as a proportion of total perfectly competitive payments.\(^{16}\)

The efficiency measure was computed as the total consumer and producer surplus generated by the auction.\(^ {17}\) The efficiency measure was normalised by computing the theoretical maximum surplus achievable (the area under the grey true value curve in the lower figure), and dividing out-turn efficiency by maximum efficiency. In all cases, only revenue and efficiency in the auction are computed and compared (for the reasons presented in subsection 4.3.2).

A total of 17 sessions each comprising 20 auctions were conducted, al-

\(^{16}\)Normalisation was necessary because valuation curves differed by small random amounts within a series of experiments.

\(^{17}\)In the example of Figure C.1, Appendix C.1, it is the total area under the “envelope” represented by the light grey aggregate true valuation function for the auction (the top figure), up to the supply level of 4 units. In this case, it is $5 + 6 + 4 + 6 = 21$ units.
though in two cases only the first ten auctions were recorded due to software glitches. There were 8 discriminatory auctions, and 9 uniform auctions run. The two sets of partial data came from the uniform auctions.

The raw experimental outcomes are presented in four graphs below: for each of the uniform and discriminatory cases, the graphs plot normalised revenues and efficiency in each session.\textsuperscript{18}

Rounds 1 to 10 are without a secondary market, while rounds 11 to 20 are with secondary market trading.

Figure 4.3: Efficiency in the discriminatory auctions.

4.3.2 Analysis

The aggregate data was analysed to examine efficiency and revenue properties of the auctions, while disaggregated, bid-level analysis was carried out to

\textsuperscript{18}Each session is represented by a distinct symbol in each plot.
Figure 4.4: Revenue in the discriminatory auctions.

Figure 4.5: Efficiency in the uniform auctions.
examine shading behaviour.

The aggregate analysis of the experiment presented below considers only revenue and efficiency at the auction stage of the game, and not, in the case with a secondary market, of both the auction and the secondary market. The reasons for this restriction of the focus are as follows:

**Auction Revenues** The policy context of this experiment is the negotiation between the regulator and the natural monopolist of an appropriate auction form. Even in the presence of a secondary market, the natural monopolist cares only about auction revenues.

**Auction Efficiency** The regulator's duty is to establish rules that will produce an efficient allocation of gas storage capacity. If there is an efficient secondary market then the regulator's task is simple: any initial allocation will be made efficient in the secondary market, and the auction
form is not an issue. In reality, uncertainty over the depth, liquidity and proper functioning of the secondary market in fact led the regulator to aim for efficient allocations post auction (see, for example, OFGAS (June 1998) for statements to this effect). In the context of the experiment, the discounting of secondary market profits relative to auction profits makes this aim coherent: social surplus is maximised by an efficient auction allocation.

A regulator facing an environment with an inefficient secondary market would have a significantly harder task of designing auction rules to maximise surplus subject to the inefficiencies downstream. Although an important and interesting question, experimental methods would need to model the secondary market more realistically than has been done here to capture these effects. In particular, the sources of inefficiency in the secondary market, like the market power and informational asymmetries of the players, would have to be modeled and endogenised, rather than treated as an exogenous “unattractiveness” roughly captured by a discount factor. A regulator facing an apparently efficient secondary market might nevertheless want to aim for efficiency in the primary auction as a “belts and braces” policy. In the case of the gas market, this point gains force from the observation that at the time of writing, the largest participant in the secondary market, Enron, had filed for bankruptcy, and there is intense speculation that the number two in the market, Dynergy, may do the same.

There is some theoretical interest in the question of how to chose auction
formats in the presence of efficient resale markets, although this concentrates on the seller’s perspective and revenue rather than the market designer’s perspective. Ausubel and Cramton (1999) consider efficient auctions with efficient resale markets, and argue that efficiency in the primary auction is even more important with perfect resale than without any resale:

Our results [...] provide a new defence for emphasising efficient auction design rather than “optimal” auction design. The presence of a perfect resale market forces even the most selfish seller, whose sole objective is maximising revenues, to focus out of necessity on efficiency. While the Coasean assumption of perfect resale is admittedly extreme, it still may better approximate outcomes in many markets than the standard assumption of no resale which the auction literature routinely makes [...] We show that the possibility of resale undermines the seller’s ability to gain by mis-assigning the good. The best that the seller can do is to conduct an efficient auction, perhaps withholding some quantity of the good. All quantity is awarded to those with the highest values.

Ausubel and Cramton (1999)’s analysis provides a prima facie argument both that the auction should be an efficient one, and that there should be no conflict of interest with the natural monopoly with respect to efficiency, although there may still be with respect to reserve price.\(^\text{19}\)

\(^\text{19}\)This conclusion adds irony to the fact that the only efficient multi-unit auction mechanism was rejected by both sides when proposed by ELSE. ELSE presented a multi-unit ascending Ausubel (Vickrey) mechanism for the purpose, but was laughed out of court for being “boffin-ish”!
The results of the experiment suggest that in our setting, when one is looking at the choice between two inefficient auctions and a possibly unattractive secondary market, the more efficient auction still revenue dominates the less efficient. It is encouraging that Ausubel and Cramton (1999)'s conflict-reducing result holds in this imperfect setting too.

**Bid-Level analysis**

The bid-level analysis concentrated on two questions: a) was behaviour consistent with Private Value or Common Value perceptions in the secondary market treatment, and b) was shading behaviour consistent with theoretical expectations? Each is considered in turn.

**Private Value versus Common Value behaviour** The model of the secondary market introduces a theoretically messy mixture of a PV and a CV setting, with PVs above the secondary market price and CVs below it. Appendix C.1, Section C.1.2 provides a detailed description. We have not investigated the theoretical equilibria of this set-up. We hypothesise that the PV part of the valuation curve seems a natural one for subjects to focus on, and this for three reasons:

1. Secondary market profits were discounted;
2. It requires reasonably sophisticated reasoning about the set-up to understand that a CV element of demand is added by the introduction of the secondary market, and no particular hints in this direction were provided in the software;
3. By construction, the allocation after the secondary market will only cover the PV portions of demand.

Subject behaviour was examined to determine whether the shift to the secondary market condition changed bidding behaviour in a way consistent with the theory of CV bidding. Two hypotheses were considered:

1. That the secondary market would have significantly more bidding outside the private value curve;

2. That the correlation between bid slopes and valuation slopes would be lower for the secondary market condition.

The first hypothesis was tested by constructing a measure of "over-bidding" for each bid in the auctions with and without secondary market, and checking that the distributions of over-bidding were both significantly different and different in the expected direction. We were expecting more over-bidding in the secondary market condition. The measure of over-bidding chosen was the total area of the bid function above the valuation curve, normalised by the valuation curve. For any point where the bid exceeded the valuation, the percentage excess was recorded. The aggregate over-bidding measure was constructed as the sum for each bid function, value function pair of all such percentage over-bids. The results are reported in Table 4.3. They show significant differences in the conditions, but in the unexpected direction: there is less bidding outside the value curve in the treatment with a secondary market. This result makes it seem unlikely that bids differed signifi-
significantly between the two treatments *because* of the introduction of a CV portion to the subjects' valuations.\(^{20}\)

<table>
<thead>
<tr>
<th>Mass of Overbidding (1)</th>
<th>Average, Last 4 rounds (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>No Secondary</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
</tr>
<tr>
<td>Discriminatory</td>
<td>No Secondary</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
</tr>
</tbody>
</table>

(1) Measured as the area under bid curve minus the area under the value curve whenever the bid is greater than the value. The area is normalised by dividing by the area under the value curve.

(2) All averages significantly different at the 95% level using single factor ANOVA

Table 4.3: Total over-bidding with and without the secondary market

The sense of the second hypothesis arises from the observation that in an auction where subjects have private values, bids should be correlated to some degree to valuations. Even in the extreme cases of bid-shading described in Ausubel and Cramton (1998) and Binmore and Swiezbinski (2000), bidding outside the subject's value curve does not make sense. This is no longer true for a common value auction, in which "speculative" engagement in the after-market allows a subject's own true (common) valuation to be as large as the market aggregate demand—after all, if bought at a low enough price, the subject can re-sell to the whole market at a profit. We would not expect bids to be correlated to private values: the whole point of a CV framework is

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\(^{20}\) It seems likely also that more experienced bidders would be needed to exploit the speculative buying opportunities.
that there is no PV reference point. In this simplified setting, as long as the secondary market was recognised as creating a "common value" framework, we would expect bids and private valuations to become de-coupled.

The second hypothesis was tested as follows:

1. For every bid curve by every player in every auction, the correlation coefficient of the points on the valuation curve to the points on the bid curve was computed. A coefficient of 1 would have indicated that the only difference between bid and valuation was a translation (as hypothesised in Berhneim and Whinston (1986)'s restriction of "k truthfulness"), whereas a coefficient of 0 would indicate an absence of any linear relationship. The $r^2$ of each bid/value correlation was computed.\footnote{Theoretical attention has concentrated on the interesting case in which valuations are common, but some private information signal is received by bidders prior to bidding: this is the configuration that produces the phenomenon of the winner's curse—see, for example, Klemperer (2000). The secondary market model simulated here does not have relevant private information disclosed to bidders before the auction, and so is a simpler case than considered in most of the common value theoretical models. Bidders find out about their own true valuation curves before the auction, which translate into a portion of aggregate demand in the secondary market, and thus are potentially a price-correlated signal. However, all bidders see a range of possible curves for the other players; moreover, they have no way of telling whether their own valuation curve is unusually high or low. Their own bid curve therefore does not obviously provide them with an informational advantage over any other bidder. It may be that in a strict statistical sense, some degree of correlation exists between the strictly private information embodied in the value curve and the final secondary market price, but it is judged for the purpose of this analysis that this relationship can be ignored, because such a relationship would be so hard to discover in the context.}

\footnote{The $r^2$'s of these regressions were typically high, ranging from a low of 82% for the average $r^2$ on the discriminatory secondary market condition (with a standard deviation of 12%), to a high of 90% (with a standard deviation of 10%) for the uniform auction with no secondary market. In other words, the linear regressions on valuation were typically good models of bidding.}
2. The resulting data was split into uniform and discriminatory auctions, and further into cases with and without a secondary market. Furthermore, only the results of the last three auctions of each series was taken, to ensure that subjects were beyond any early learning phase. The data was split into auction types because of the very basic bid-level behaviour difference expected (and found) between the auction forms. The data was split into with and without secondary market sets in order to test for the significance of the move to a CV context.

3. An analysis of variance was performed on the distribution of correlation coefficients to check for the significance of the shift from the absence to the presence of the secondary market.

Table 4.4 summarises the result of the hypothesis test: in the uniform case, the average level of correlation was high, but there was no significant difference between the treatments with and without a secondary market; in the discriminatory, the correlation levels are significantly lower, and there is a significant difference between secondary and non-secondary treatments. Note that under a pure common value treatment, one would expect a correlation coefficient of zero, whereas here we have an average of 0.46. The reduction in correlation coefficient goes in the right direction for it to be accounted for by a move to a partially CV framework for the discriminatory auction. However, this

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23Appendix B.1 suggests that only the first four auctions need be taken as constituting the learning phase. The decision was made to further restrict the data set in this analysis in order to be very confident that simple learning effects were minimised.
is the only one of four tested effects that go in the expected direction, and one would therefore advise caution before rejecting the hypothesis that some other effect is at work.

<table>
<thead>
<tr>
<th>Average Correlation of Bids and Valuation Functions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>0.92</td>
</tr>
<tr>
<td>No Secondary</td>
<td>0.92</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
</tr>
<tr>
<td>Discriminatory</td>
<td>0.59 **</td>
</tr>
<tr>
<td>No Secondary</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>0.46 **</td>
</tr>
</tbody>
</table>

** Significantly different means at 95\% confidence (ANOVA)

Table 4.4: Average correlation between bids and valuations

We conjecture, but do not further test, that in this context it is most useful to think of the secondary market as a competing market place for sourcing privately valued gas storage. The uniform auction presents the bidder with some safe and simple options—like bidding very close to the valuation curve—while the discriminatory auction requires more thought, work, and risk. Thus, the conjecture is that the discriminatory is an unattractive market place in which to source gas compared to a simple secondary market, whereas the uniform holds its own. This conjecture is consistent both with the lower bid-to-valuation correlations in the discriminatory with secondary market: subjects “flatten” their bid curves in the knowledge that there is a substitute source of gas, and with a reduced level of over-bidding—subjects are substituting demand from the auction to the secondary market.

**Shading behaviour** To a first approximation, shading can be thought of as being comprised of two components:
1. How "flat" the bid curve is relative to the value curve, and

2. To what extent is the bid curve translated towards the origin relative to the value curve.

The theory of risk averse bidders in multi-unit discriminatory auctions suggests that bid curves should be flat, and the theory of multi-unit uniform auctions suggests that there are some very attractive equilibria from the point of view of the bidders which involve highly translated bid functions. Measures of both types of shading were analysed against these predictions.

The “flatness” of bid curves was measured by the same correlation coefficient as used to look for Common Value effects on page 131. The distribution of correlation coefficients between bid functions and value functions for the two auction types is shown in Figure 4.7 (averages for these distributions are presented in Table 4.4). These distributions convey visually that in all conditions, the discriminatory auctions seem to have a lower regression coefficient than the uniform auctions. Although the theory of bidding in uniform auctions suggests no particular relationship between bids and values, the theory of multi-unit discriminatory bidding (see, for example, Anwar (1998)) suggests that there should be no correlation between the slopes of valuation functions and the bid function if bidders are risk averse. Although we do not see no correlation here, we certainly see less of one when compared to the uniform.

The result accords well with intuition about behaviour by risk averse
bidders: in the discriminatory auction, the *ex post* best bid is to have submitted a flat schedule securing a maximum amount below the valuation curve; however, *ex ante*, the bidder will be tempted to submit some degree of slope, since this is insurance against obtaining nothing at all. But the more the bid resembles the valuation curve, the more profits tend to zero. The motive that pushes bids closer to valuations is risk aversion, whereas the motive that pulls them apart is profit maximisation. The uniform auction does not impose such a strong profit penalty for bids close to the value curve—such a bid will induce low profits only on marginal units.

![Normalised Frequency Distributions, Correlation of Bids to Valuations - Uniform](image1)

![Normalised Frequency Distributions, Correlation of Bids to Valuations - Discriminatory](image2)

Figure 4.7: Distribution of Correlation Coefficients between Bids and Values
An average shading metric was constructed to examine the impact of auction form on the level of shading. The bid to valuation correlations are one measure of shading, and point to significant differences in the shape of bid curves in the two auction forms. A explanation for this difference is sketched-out on page 135. However, the bid-valuation correlations are silent on the level of the bid curves. The metric built to analyse the aggregate level of shading is the total area under the bid curve divided by the total area under the valuation curve, for the first twenty units of the bid.

Table 4.5 shows the average over all bids and all players of the shading measure. An ANOVA determines that the discriminatory auction induces significantly more shading than the uniform, and that the discriminatory with a secondary market is significantly more shaded than the discriminatory without. While theory is silent on the level of uniform shading (because of the multiplicity of equilibria, some of them highly shaded), it is clear that it is very important to shade in the discriminatory auction: no translation of the bid curve as against the value curve in the discriminatory would be associated with low or non-existent profits in the discriminatory, but adequate profits in the uniform.

The apparently low level of shading in the uniform provides a challenge for future experimental work: what does it take to reproduce the extreme equilibria posited by the theory of uniform auctions? The

\[24\] Shading also increases markedly as the rounds progress for the discriminatory, but any such movement is much less marked for the uniform.
field experience of the UK Pool (see Chapter 3) suggests that the vast amount of repetition in this market may have contributed to the discovery of these equilibria.25

<table>
<thead>
<tr>
<th>Average Shading Levels (1)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>1.14 **</td>
<td></td>
</tr>
<tr>
<td>Discriminatory</td>
<td>0.79 **</td>
<td></td>
</tr>
<tr>
<td>Uniform No Secondary</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Discriminatory No Secondary</td>
<td>0.93 **</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>0.66 **</td>
<td></td>
</tr>
</tbody>
</table>

(1) Shading metric is Area Under Bid / Area Under Valuation for the top 20 Units of bid
** - Averages differ significantly at 95% using ANOVA

Table 4.5: Average Level of Shading, Uniform and Discriminatory

Aggregate Revenue and Efficiency Properties

The economic (as opposed to statistical) significance of the treatments is summarised in Tables 4.6 and 4.7. These two tables report aggregate summary statistics for the last three auctions of each treatment.26

Table 4.6 reports aggregate summary statistics by condition. Average normalised efficiency ranges between 89% and 95%, with standard deviations ranging between 5% and 19%. These are “high” efficiency levels in all cases (where “high” can be thought of as being defined against the empirical “zero-intelligence” benchmark proposed in Appendix A.1). Average normalised revenues range more widely in the last three auctions than does efficiency,

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25 In such a case, it is not clear that the one-shot equilibrium explanation is necessary to explain the facts.
26 Earlier auctions were excluded to ensure that subjects were beyond any early learning phase. See footnote on page 132.
with values between 68% and 114%. In all but one condition, revenues are lower on average in the last three auctions than they would have been in a competitive market, indicating that in aggregate and on average, subjects shade their bids in both auction forms.

Table 4.6: Summary Aggregates for Uniform and Discriminatory Auctions

Table 4.7 computes aggregate average measures of the economic significance of the policy choice variable—Uniform or Discriminatory. The absolute difference between the Discriminatory and Uniform auctions is reported, as well as this quantity as a proportion of average surplus revenue levels (the average being taken over all conditions). The fact that the market being represented was one which generated £12m in a discriminatory auction in 1998 is used to compute a very rough "order of magnitude" statistic for the auction choice. It is assumed that the £12m of revenue is equal to the average revenue over all treatments; this assumption allows the translation between experimental results and market magnitudes. The measure, ob-

\[ \text{Table 4.6: Summary Aggregates for Uniform and Discriminatory Auctions} \]
Previously rough, is intended to indicate very broad patterns. The last two columns of Table 4.7 show that the revenue significance of the auction choice appears to be more significant than the efficiency significance (with the one exception of the low elasticity secondary market case). The implication is that the natural monopolist might gain or lose some millions of pounds per year depending on the auction choice, whereas the consumers might between them gain or lose hundreds of thousands of pounds, or, in just one case, a few millions of pounds.  

<table>
<thead>
<tr>
<th>Economic Significance of Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>No Secondary Market</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Secondary Market</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

(1) Surplus from Discriminatory minus Surplus from Uniform  
(2) Revenue from Discriminatory minus Revenue from Uniform  
(3) The Gas Storage Auction at Hornsea raised £12m in 1999.  
We assume that this is the average revenue in computing a measure of economic significance, meant to indicate an order of magnitude.  
Results of last 3 auctions of each treatment only

Table 4.7: Economic Significance of the Auction Type

The aggregate efficiency and revenue data was further analysed for statistical significance using dummy variable Ordinary Least Squares regressions. A summary of the statistical results is presented in Table 4.8. The table enumerates only the significant relationships found in the two data sets.  

valuation functions, and the true perception of the nature of the secondary market was unknown.  
28The auction design was in fact a greater pre-occupation of the natural monopolist’s than of the regulator’s or of customers’. The order of magnitude statistic is consistent with this.  
29All regressions were run with learning (as described in Appendix B.1), auction-type and elasticity dummies. The analysis was also performed with a set of group variables to check any experiment-specific effects. The group controls were not found to be significant, and dropped from the final regressions.
CHAPTER 4. UNIFORM OR DISCRIMINATORY IN UK GAS?  140

Table 4.8: Summary of Statistical Results

With no secondary market, the only statistically significant variable in the determination of auction efficiency was the learning effect, with higher inefficiency in the four early learning periods. Auction revenue with no secondary market, on the other hand, is significantly increased by a discriminatory format, by low elasticities and by early stage learning. Each is considered in the light of prior expectations.

**Discriminatory Format** generating higher revenues is consistent with the prediction described on page 111.

**Low Elasticities** generating higher revenues suggests that the "surplus-at-risk" effect (see page 111) dominates the "strategic" effect of low elasticities. One might expect the strategic effect of elasticity to be more important in uniform than in discriminatory auctions, because the pay-off impact of marginal shading is greater in a uniform than a discriminatory auction. This hypothesis was tested by adding a composite
interaction dummy to identify the subset of data with both uniform auctions and low elasticity. It was found that low elasticity in the uniform is, on average, significantly associated with lower revenue. This is consistent with the prediction that the strategic effect of elasticity should be more important in the uniform.

**Early Stage Learning** periods yield higher revenues: subjects learn to leave less surplus to the seller.

In the data with a secondary market, we find that the uniform auction is significantly more efficient, with no other variables having a significant impact on efficiency.\(^{30}\) Auction revenue is significantly increased by high elasticities and a uniform auction type. Learning is not significant in either the efficiency or the revenue regression. Section 4.3.2 presented evidence to show that the presence of the secondary market encouraged a greater increase in shading in the discriminatory than in the uniform case. At the aggregate level, this is showing as discriminatory revenues being significantly reduced by a move to a secondary market. The elasticity result suggests that the strategic effect of elasticity dominates the surplus-at-risk effect in the presence of a secondary market. This result is consistent with the view that when there is a "second chance", players are more willing to take strategic risks, like increased shading, since a basic level of surplus is guaranteed by the operation of the almost frictionless secondary market.

\(^{30}\)Some reasons why efficiency continues to be of some policy interest, even in the presence of an *ex hypothesi* efficient secondary market, are given on Page 126 and following.
Discussion and Conclusion

The policy question set for the experiments was "uniform or discriminatory?" The statistical results suggest that the answer is clear: a discriminatory auction if there is no secondary market, and a uniform if the secondary market is as modeled. Note that there is no conflict of interest between regulator and natural monopolist with regard to the auction form: in the case in which the natural monopolist prefers the discriminatory, the regulator is (statistically) indifferent; in the case in which the regulator prefers the uniform, so does the natural monopolist. This result goes in the same direction as the theoretical result of Ausubel and Cramton (1999), who show that efficient auctions are revenue-optimal when there is an efficient secondary market. The experimental result is that, in the cases tested, the revenue-dominating auction with a secondary market is also the efficiency-dominating auction, even when the auction is not perfectly efficient. Moreover, without a secondary market, neither auction type is significantly different from an efficiency perspective.

During the course of the auction negotiations, the regulator and the natural monopolist never agreed on the preferred auction form, nor did they concentrate resources on analysis and modeling of the market. The natural monopolist had a strong prior that it would be better served by a discriminatory auction, and the regulator had a similarly strong prior regarding the uniform. Both sides were so used to conflictual relations that a concordance of interests in this matter would have seemed surprising. Moreover, the negotiations at several points threatened to degenerate into costly litigation: the consequences of this apparent conflict could easily have spilled over into
other areas of the gas market.

The experimental results suggest that matters of fact may have more to do with appropriate auction form choice than differences in interests. The presumed differences in interest that in fact prevailed could have had costly consequences for the gas market. Thus, the conclusion is a heartening one for market design, in that it may be possible to dissolve policy conflict and avoid costly outcomes by careful and persuasive modeling of markets.

A caveat to this conclusion regards some of the "convenience" modeling choices made. The treatment of the secondary market could be made markedly more realistic, especially with regards to endogenising the frictions that can expected. The experimental treatment of "with" and "without" secondary markets should probably be modified, with different subject groups subjected to the different treatments. Repetitions should be conducted between "blind", randomly shuffled groups, rather than always with the same group. Finally, if the complexity of the resulting set-up should be too great for inexperienced bidders, some attempts to use experienced bidders, even industry participants, should be used.
Chapter 5

The Promise of Agent-Based Models

5.1 Introduction

In Chapters 2 and 3 some traditional economic analysis tools were applied to market design questions. Whilst the theoretical and empirical approaches of these chapters yield useful insights, the analysis presented has limitations. The highly stylised representation of agents and their environment in Chapter 2 is a priori of concern when seeking applications—how are we to judge whether the world is importantly different? Has the modeler made the right simplifications? These are all questions which cannot be answered within the model. The empirical approach of Chapter 3 raises another set of concerns—the careful empirical analysis is essentially retrospective, and cannot easily be translated into the prescriptions needed for market design purposes. In particular, the identification of a necessary condition for the bidding ineffi-
ciencies in the UK Pool as being the natural gas contracts entered into by the electricity generators does not itself suggest any remedy. Was the contracting intrinsic to British Gas's market power, or to the structure of the electricity market, or to the nature of gas extraction or electricity production? The empirical analysis did not in itself tell us where to look for a solution.

This chapter will consider a number of simulation models that try, in varying degrees, to be prescriptive in the detailed way required by market design problems. To do so, they combine theory with a close anchor into institutional details. The models considered are listed in Table 5.1.

<table>
<thead>
<tr>
<th>Models</th>
<th>Market Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fehr &amp; Harbord (1993)</td>
<td>UK Electricity Market power</td>
</tr>
<tr>
<td>Green &amp; Newbery (1992)</td>
<td>UK Electricity Market power</td>
</tr>
<tr>
<td>Testafson (2001)</td>
<td>Generic Electricity Market power</td>
</tr>
<tr>
<td>Bunn &amp; Oliveira (2001)</td>
<td>UK NETA Rule re-Design</td>
</tr>
<tr>
<td>Unver (2001)</td>
<td>UK Medical Interns Market Institutions</td>
</tr>
</tbody>
</table>

Table 5.1: Prescriptive simulation models

All of them except Unver (2001) relate to electricity markets, and this last is included as an exemplar of what can be achieved using learning agent simulations. Fehr and Harbord (1993) and Green and Newbery (1991) were early applications of “applied theory” and structural econometrics to the market power issues that surfaced in the UK power pool. These analyses were the starting point for this author's contributions to the analysis of power pools ((Curzon Price 1999) and (Curzon Price 1997)), in which some of the shortcomings of earlier modeling work are addressed by applying agent-based simulations. These modeling results produced some (relatively narrow) extensions to the Fehr and Harbord (1993) results. Three other
learning-agent models are surveyed to provide a more complete account of the methodological pluses and minuses of agent-based methods for market design purposes. Some possible reasons why the agent based models in Curzon Price (1999), Curzon Price (1997) and Bunn and Oliveira (2001) fail to match the successful analysis of Unver (2001) are offered.

5.2 The Context and Prerequisites of Mechanism Design

Nelson and Winter (1982, page 372) argue that “the ability of a theory to illuminate policy issues ought to be a principle criterion by which to judge its merit.” This understandable desire to illuminate policy leads one to seek modeling tools that lead to better predictions about social systems. Curzon Price (1999) uses the phrase “Computer Assisted Economic Design” (“economic-CAD”) to represent the goal for the modeling tools: the model should be a detailed representation of the social process, where agents are represented by intelligent, learning processes (“learning-agents”). The ultimate aim for “economic-CAD” is to increase the productivity and quality of applied mechanism design work.

In general, the process of mechanism design can be characterised as follows:

- Define the objective.
- Specify the agents who will be involved in attaining it, and what their interests are.
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- Design a set of rules and incentives such that the agents, when following the rules and striving for outcomes in their own interests, will together promote the objective.

A mechanism thus tries to make it in each agent's self interest to act in such a way that the system in aggregate move towards a given objective. The objective is then proof against selfish subversion: it relies only on people pursuing their self-interest, and no more. As an example, take the Prisoners' Dilemma. We often think of this game as a tragic story about wasted surplus when cooperation is unsustainable. However, note that the original narrative is one of mechanism design: how to get prisoners to indict themselves without any need to tamper with the evidence.\(^1\)

Mechanism design is an increasingly practical discipline. Large organisations are looking for effective ways to decentralise. This is happening in governments, corporations and bureaucracies. We can think of markets as composed of a huge diversity of micro-institutions that work as mechanisms in the sense given above. These institutions sometimes need to be planned and designed in their microscopic detail in a way that might have seemed unthinkable to those who once railed against bureaucratic over-regulation.\(^2\)

\(^1\)The original story around the Prisoners' Dilemma is the following: two suspected prisoners are put into non-communicating cells. There is not enough evidence to convict the prisoners without testimony. An unscrupulous police officer says to each in turn: "If you testify against your accomplice (fink) and he does not (cooperates), then you get off, and he is locked up for twenty years; if you fink and he finks, you are both put away for ten years (because I give you some credit for finking); if neither of you fink, then I have the evidence to put you both away for six months." The logic of the dominant equilibrium is well-known: if my colleague cooperates, I prefer to fink; if he does not, I prefer to fink; so whatever happens, I fink. The mechanism described is that of a set of evidence rules under a hypothetical judicial system. It is the mechanism which induces incriminating behaviour. Note that incrimination does not depend one jot on the truth of the matter, just on the incentives.

\(^2\)The irony is apparent to watchers of regulatory politics in the privatised utilities in
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Increasing understanding of mechanisms allows new rules to be grafted into old contexts, like the organisation of energy markets, without proceeding entirely blindly. These "designer markets" are being examined against performance objectives, and reforms occasionally implemented. In the UK, for example, this has happened in most of the utilities, in the provision of healthcare, in education and elsewhere. This is the context for which a method for "Computer Assisted Economic Design" would be of great use.

5.2.1 Assessing Real Mechanisms

Applied mechanism design will typically require an assessment and critique of current mechanisms, followed by proposals for alternative mechanisms. A mechanism ("to sell electricity", for example) is usually made up of a large number of interrelated rules. What sorts of models do we want when assessing the design of this system?

In the case of an engineering design problem, theory, simulation and controlled experiment are all ways of generating predictions. The analogy with mechanism design holds well. Decision theory's many variants provide some predictions. These are often general predictions ("this mechanism is

Increased understanding is not a sufficient condition. Today's power pools, for example, would be unthinkable without real-time control and the computing resources needed to act rapidly on market signals.

In contrast, a more theoretical approach to mechanism design asks: "given these constraints, what is the optimal mechanism for the job." Optimal mechanisms derived under the current state of the theoretical art seldom look like actual institutions. Mechanisms are shaped by the negotiations that give birth to them; so the only viable form of policy advice is often to rank alternatives that are "on the table" rather than devise optimal schemes.
optimal in a second-best framework"), that are weakened to the extent that they are strictly only true of the behaviour of an idealised system. The inductive hope is that theory's predictions will nevertheless generalise, and to check this empirical methods must be used. Moreover, there often are no theoretical predictions for particular configurations of rules and agents, or the research effort required to build and solve a specific "applied theory" model may be too large, or its success too uncertain. As in the engineering case, the hope for "economic engineering" is that solutions can be found that combine computer simulations of various sorts, or laboratory experiments, or field trials if the money is available to fund them.

5.2.2 Towards Computer Assisted Economic Design

The perfect model for testing detailed hypotheses about mechanisms is a very faithful representation of the social system. The environment would be more realistically described than in a laboratory experiment or a bespoke "applied theory" model, and agents would have realistic limitations on their powers of reasoning.\(^5\)

The electricity market is a good testing ground for "economic-CAD". It is one of the largest markets in which competition and decentralisation have been implemented, so any progress in design may have sizeable direct

\(^5\)For some very sensitive policy innovations, governments and firms run pilot projects. In the UK, this has happened for example for the introduction of full retail competition in the gas market, for the introduction of vouchers for nursery school education, for the poll tax (early introduction in Scotland), and for the notorious "rubber windmill" exercise for the "internal market" NHS reforms. The same happens in clinical drugs trials. But it is not clear that these are always run for experimental purposes, rather than propaganda reasons, and in any case, cheaper alternatives would be welcome. Moreover, the lessons learnt from careful application of Computer Assisted Economic Design methodologies could lead to more careful pilots.
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economic benefit. Moreover, the economic importance of the market means that it has been thoroughly investigated by other modelers: it provides good ground for a comparative approach to modeling for market design. Finally, there are some respects in which electricity is very close to an economic textbook good: it is a homogeneous and non-storable good. Both these factors considerably simplify the modeling of the spot market for electricity, as long as it is considered appropriate to ignore transport costs.

However, electricity has a number of special characteristics which make it unlike the textbook abstraction of a good: its efficient provision involves regulation of a natural monopoly transmission system and a vast coordination exercise. Moreover, spot market trades are repeated about 18,000 times a year, and the players are few, with large capital commitments. Both these are factors which one would expect to reduce competitive pressures in the market. The institutional context of natural monopoly makes the design questions pressing ones, but restrict the generality of the conclusions reached in this market.

An ideal "economic-CAD" model of a power pool would have the following characteristics:

- A detailed engineering representation of electricity supply: production functions for actual power plants on the system together with a sufficiently detailed representation of the distribution network to capture strategic opportunities offered by locational pricing;

- a good econometric representation of consumers' demand: totally inelastic short run demand for power is usually taken as a good approx-
imulation of the demand-side in electricity markets, since end-users do not see prices fast enough to change their consumption patterns (this may change with the gradual introduction of "smart" meters);

- agents who will represent producing firms, consumers, the natural monopolist transmitter, and possibly even the regulator;

- a set of rules and incentive schemes that the agents will be constrained by: the market design exercise is a search for a good such set of rules and incentive schemes.

Structural models that contain the first two elements to some degree exist today. Electricity supply is still a centrally planned activity in many countries and planners have developed very sophisticated representations of their market. For mechanism design purposes, the planners' model must be augmented with agents and rules. These agents will represent producing firms, consumers, the natural monopolist transmitter etc... Their supply and demand characteristics are now considered constraints on the agents. The rules are also constraints, but the modeler may change these.

The aim of the model is to predict the behaviour of agents under the relevant constraints when given long enough to adjust to an environment. Economic-CAD should generate predictions about the system aggregates in an environment that is a close representation of the one that will be faced.

5.2.3 Some Modeling Compromises

Since we are a long way from being able to build the complete economic-CAD system for electricity, one must hope to stop the gaps with judicious
modeling choices. One difficulty is the trade-off between agents' rationality and the realism of the representation of the engineering environment.

The agent-based approaches of Curzon Price (1999), Curzon Price (1997) and Bunn and Oliveira (2001) have sub-rational agents and (passably) faithful representations of the environments. Other approaches (most notably Green and Newbery (1992)) involve calibrating "off-the-shelf" industrial organisation models, or building specific models for the task (for example, Fehr and Harbord (1993)). In such cases, the equilibria found will be the equilibria of entirely rational agents, and the environment may be at a considerable remove from that relevant for policy purposes.

This section concentrates on the approaches of Green and Newbery (1992) and Fehr and Harbord (1993). The attractions of the agent-based approach can be understood by reference to the limitations of current approaches.\(^7\)

<table>
<thead>
<tr>
<th></th>
<th>Agent-Based</th>
<th>Fehr &amp; Harbord</th>
<th>Green &amp; Newbery</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Nature&quot;</td>
<td>Good</td>
<td>Poor</td>
<td>Medium</td>
</tr>
<tr>
<td>Rules</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Agents</td>
<td>Learners</td>
<td>Rational</td>
<td>Rational</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Learning</td>
<td>Nash (reduced multiplicity)</td>
<td>Nash (selected off-model)</td>
</tr>
<tr>
<td>Selection</td>
<td>Dynamic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2: The modeling choices represented by two "current art" techniques and by the Agent-Based approach.

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\(^6\)In Green and Newbery's case, the Klemperer and Meyer (1989) supply function equilibrium model.

\(^7\)This by its nature has to be a rather detailed and specific critique of the best practice models. A good introduction to the institutional and technical details of the new power markets is given in Hunt and Shuttleworth (1996).
Table 5.2 summarises the choices made in the three approaches. Fehr and Harbord confine themselves to a very stylised representation of the external environment of the market: in particular, firms have constant marginal costs, whereas generating technologies clearly demonstrate increasing marginal costs. They have a good representation of the rules capturing the discrete-bid increments and unit-size of the generators\(^8\) and the fact that a uniform price auction is close to the method used by the market to allocate units and set prices. However, the representation of the pricing rule is clearly an abstraction, and the model must remain silent about the impact of the deviations of the actual market from the uniform auction. Their agents are rational players who settle on a Nash equilibrium; the potential multiplicity of equilibria is reduced by careful attention to the rules and restrictions on the supply side. They characterise just one mixed-strategy equilibrium but do not show that it is unique.

Green and Newbery make some different compromises. The "physics" of their model allows for increasing marginal costs. However, the consumer-side of the market (treated in all these models as an immutable part of the environment) is poorly represented: consumption is assumed to have a high price elasticity (-0.25), against all the evidence (see, for example, DTI (1994a), DTI (1994c), DTI (1994b)). The rules are represented by a highly reduced form, in which players submit continuous supply functions. The agents are simply

\(^8\)A major theoretical interest of Fehr and Harbord (1993) is that the introduction of discrete bids reduces the multiplicity of equilibria standardly found in multi-unit uniform price auctions (see, for example, Klemperer and Meyer (1989)). It is not obvious, however, which model is the more relevant. Whilst bidders do have to submit discrete bids in the England and Wales pool, it is a matter of human and institutional psychology whether small increments lead to behaviour best modeled by continuous functions.
characterised as settling on a Nash equilibrium. The framework that they adopt (Klemperer and Meyer 1989) permits an infinity of supply function equilibria, from aggressive Bertrand to accommodating Cournot. For the purposes of counterfactual simulation, the equilibrium selection problem is resolved off-model.⁹

Fehr and Harbord build a piece of theory specifically for the type of auction conducted in the UK electricity spot market. Tractability keeps them to a simple representation of the environment. However, it allows them to provide a strong argument for a particular mechanism reform,¹⁰ and draws attention to the influence of ownership structure on outcomes. However, the model can be suggestive, but will not provide predictions about specific mechanisms because of the lack of realism required to keep the model tractable.

Fehr and Harbord’s model and Green and Newbery’s make very different choices with regard to the detail that they include. Many of the latter’s choices seem to be imposed by the choice of Klemperer and Meyer’s framework. For example:

1. Making bid functions twice continuously differentiable. Fehr and Harbord (1993) show that the Klemperer and Meyer results do not hold with discrete bids. Particularly relevant, they show that under demand

⁹As is necessarily the case with structural econometrics, Green and Newbery’s model is not tested by the data, it is calibrated by it. Therefore, to decide whether the model is a good representation involves a careful look at the representativeness of the structure itself. The odd choice of the demand elasticity of demand parameter, together with the non-solution of the equilibrium selection problem suggests that a wide variety of policy positions could have been supported by the model.

¹⁰They propose the replacement of the uniform-price multi-unit “reverse” auction with a Vickrey auction. The model is described in a little more detail in Section 5.2.5.
variation and supply schedule commitment in the sorts of range experienced regularly in the England and Wales electricity market, there are no pure-strategy equilibria if bids are discrete, which casts some doubt on Green and Newbery's selection of a pure-strategy equilibrium.

2. They ignore elements of the price-setting process (eg "LOLP payments", that have been thought crucial by, for example, Wolak and Patrick (1997)). The supply function equilibrium is intended to mimic the daily electricity auction, and thus the setting of System Marginal Price (SMP). However, in their simulations, they report results for Pool Output Price, which is SMP added to other non-modeled components. In this case, the fit between their model and the market institutions does not seem to be quite good enough for the calibration exercise they perform.

3. They make their own selection ("off-model") amongst the multiple equilibria of the Klemperer and Meyer model;

4. They make an odd choice of demand elasticity.

The last of these seems particularly damaging to the persuasiveness of their model, since it appears to be a straightforward and significant error in data parametrisation rather than any issue of modeling judgement. Green and Newbery (1992, p 944) write:

Although there is some uncertainty about the correct value for the elasticity of demand for electricity, the range of parameters considered [...] almost certainly bracket the correct value.
Table 5.3: Price Elasticities of Electricity Demand for the UK, (DTI 1994a) (DTI 1994c) (DTI 1994b). The short run price elasticity for the domestic sector is undefined, since prices have until now been fixed for single year periods. That is, short-term price responsiveness has not until now been possible. This could be construed as a totally price inelastic short term demand.

It is important to take care over what period the elasticity should be taken. The Pool is a day-ahead market, so day-ahead responsiveness is the relevant measure. In Table 5.3, the short term elasticities refer to 3 months! Even over three months, residential and commercial consumers, who make up the bulk of electricity sales, are outside Green and Newbery’s range (taking the residential elasticity to be zero). It is not surprising that these consumers are insensitive to day-ahead prices: they are billed on tariffs fixed for a year, usually. There are very few industrial customers who change consumption for the next day on the basis of pre-announced prices. This casts doubt on Green and Newbery’s decision to use an elasticity of -0.25 as their central case.

Green and Newbery have two levers with which to calibrate the Klemperer and Meyer model for the UK power pool: they can decide to select the equilibrium anywhere between Cournot and Bertrand outcomes, and they can vary the price elasticity of demand within some reasonable range. They choose an elastic demand and a non-aggressively competitive equilibrium. This allows them to make a strong ceteris paribus case for increasing the
Table 5.4: Green and Newbery must choose an appropriate value for the price elasticity of demand for electricity (in columns). They must also select one of the infinity of equilibria that are supported by the Klemperer and Meyer model (in rows). The table shows the impact on calibration and policy conclusions of different choices. Green and Newbery choose the configuration that generates a good calibration and strong policy conclusions.

number of players in the market. Their choice is described in Table 5.4.

Green and Newbery are more ambitious than Fehr and Harbord, in that their model is meant as a structural model of the industry. Von der Fehr and Harbord are (“only”) looking for theoretical outcomes in this sort of auction, and they sacrifice a great deal of detail in the process. It is not surprising that Fehr and Harbord make general but limited claims to the policy maker, while Green and Newbery try to be specific, for example, about the number of firms the industry should have.

This critical account of Green and Newbery and Fehr and Harbord is intended to demonstrate that current techniques have their shortcomings, and that there is a genuine need in policy making for models that capture the details of market rules and constraints. The niche is for a model that

<table>
<thead>
<tr>
<th></th>
<th>More Elastic Demand</th>
<th>Less Inelastic Demand</th>
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<tr>
<td>Aggressive</td>
<td>Calibration OK</td>
<td>Calibration OK</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>No Policy Change</td>
<td>No Policy Change</td>
</tr>
<tr>
<td>Accommodating</td>
<td>Calibration OK</td>
<td>Calibration Problem</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Break up incumbents</td>
<td>Model policy silent</td>
</tr>
</tbody>
</table>

11 This is a conclusion that most economists would endorse on a priori grounds, but the point here is to justify a policy conclusion empirically.

12 There are also statistically based models used in these contexts. There is no reason in principle why they should not be adequate. Imagine we have a very large number of mechanisms, each with small variations of rules and outcomes. These would provide just the sort of “natural experiment” that the Computer Assisted Economic Design system tries to mimic. Wolak (1997) and Wolak and Patrick (1997) attempt to learn from the statistical properties of the electricity markets, with minimal use of structural modeling.
has a richly detailed representation of the market and its mechanisms, and makes an attempt at prediction.

Compared to the current art, the attraction of the agent-based ideal seems clear: good representation of the environment, good representation of the rules. The agents are learners, and not necessarily rational. The equilibrium selection problem, if it arises, is solved (or at least illuminated) by examination of the dynamic process of learning. Overall, the agent-based system has the potential to solve the modeling difficulties in a less arbitrary way than the current art. The next section provides a critical summary of Curzon Price (1997) and Curzon Price (1999). The other agent-based studies (Bunn and Oliveira (2001) and Unver (2001)) will be used to offer a perspective on this critical summary.

5.2.4 Steps Towards Agent-Based Design

Businesses regularly use detailed simulation models for scenario analysis, although the equilibrium thinking tends to happen outside the model. An example of an advanced use of scenario analysis is the work done by London Economics and Harbord Associates (London Economics and Harbord Associates 1995) analysing the extent of market power in the Victoria power market. A very rich representation of the market was used,\textsuperscript{14} and payoffs

\textsuperscript{13}Nash himself considered the introspective reasoner to be only one foundation for his solution concept of games. The section in which he makes a learning argument was omitted from the original published version of his PhD thesis (Nash 1950, Section 9).

\textsuperscript{14}As an indication of the representational sophistication, this simulation model computed five “model years” in approximately one “real” hour on a top-of-the-range workstation of the day.
were computed under a grid of strategies. The grid was examined for Nash equilibria. Although the results were instructive, they suffered a number of problems:

- the \textit{a priori} representation of agents as Nash equilibrium seekers and,
- the arbitrariness and coarseness of the strategy grid used.\footnote{\textit{Coarseness} refers to the number and distance between strategies. Each price bid, in this case, was a strategy.} Equilibria found under very coarse representations of strategy space often fail to survive a move to finer grids.\footnote{An outcome can be an equilibrium, for example, because of an incentive to just undercut a rival. But there may not be an incentive to undercut by a large amount.}

The agent-based design system would ideally use the strategy space actually allowed players in the market and the agents would be psychologically and organisationally plausible learners. Even the most sophisticated use of scenario models tends to treat some of the strategic aspects of markets too arbitrarily. In practical terms, this means that a reliance on scenario modeling will mean an often imperfect exploration of strategy space. Moreover, the behavioural simulations underlying an agent-based approach may suggest equilibria which are not Nash equilibria (as is the case, for example, in Unver (2001), where a theoretically unstable configuration is argued to be stable under an appropriate behavioural dynamic). Both the strategy space and the behaviour that is sought are likely to be restricted in traditional scenario analysis.

The ideal agent-based design system is what would be necessary, whilst "best practice" under current knowledge and technology for applied models is either Green and Newbery (1992)-style structural modeling, (good on
strategic interaction, bad on realism), or “London Economics and Harbord Associates” (London Economics and Harbord Associates 1995)-style scenario modeling, better on representation, but poor on strategy. The modeling compromise proposed in Curzon Price (1997) and Curzon Price (1999) has been the following:

1. Build good scenario-style structural models;

2. Isolate agents’ inputs to the simulation;

3. Use AI models to represent agents—a give them the sort of general purpose mechanical learning abilities that we can currently easily code; if these also accord with current psychological or organisational evidence on learning, so much the better.

4. Simulate the co-evolutionary dynamics of the environment-plus-agents model;

5. Treat (albeit tentatively) rest points or aggregate properties of the simulation as predictions of the modeled world.

The remainder of this section summarises the genetic algorithm simulations performed in Curzon Price (1997) and Curzon Price (1999), and shows the extent to which these simulations fall short of the ideal.

The genetic algorithm is thought to be a good general purpose search algorithm in “static” problems (that is, against a fixed environment). The

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17 These papers use genetic algorithms as the learning engines. These are convenient, and may have nice representational features themselves. However, there is no reason in principle why the approach could not “plug in” other AI learners. As a first step, the aim in these analyses was just to give agents the right sort of learning capacities.

18 Holland (1992 (1975)) provides a proof of his “schema theorem” which shows that a very simple version of the genetic algorithm implements an optimal “on-line” search
algorithm searches by a process of repeated "generate, test and select": try a solution, see how well it does, apply a selection rule, start again. In static environments, the algorithm has done sufficiently well to be regularly applied to actual and complicated operations research (OR) problems. In these applications, the GA prescribes already. It evolves rules like: "if you want to balance your network, you'd better turn up compressor number 56". It has "learnt" that "things go better in this sort of situation if you do that" from data, although this data may be from its own simulations.

What changes in the strategic case is that the genetic algorithm would have to "learn" rules like "I should turn up compressor 56 if you have turned down 57, but otherwise turn it down, and my guess is you've turned it up": the "fitness landscape" is no longer static, but varies according to others' actions, that themselves may vary depending on mine. So if each agent is represented as a GA, the best an agent can do will depend on the behaviour evolving in the other. When agents simultaneously develop rules through response and adaptation, we have co-evolution of behaviour. Figure 5.1 provides a visual representation of the difference between the use of a genetic algorithm in a "static" and in a "strategic" environment.

The idea of modeling co-evolution with GAs is analogous to a simplified version of game theorists' notion of fictitious play. Strategic environments

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19 The classic example is Goldberg's application to scheduling a gas network to achieve pressure balance in real time. There are now a large number of GAs being used in OR problems.

20 The algorithm has only "learnt" in the sense that this rule has done better than other rules in the past, and so has survived the selection phase. There is a very nice basic description of the way that machines can learn by "bootstrapping" in Holland (1997). Holland provides an account of the way Art Samuel programmed his draughts player to get better and better at the game some thirty years ago.
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Maximise the payoff given that you can vary the strategic variable between 0 and M

Agent 1's profit-maximising choice given agent 2's behaviour

Agent 2's profit-maximising choice given agent 1's behaviour

Figure 5.1: Searching through "static" and "strategic" landscapes. The top diagram is a representation of a GA's search on a one-dimensional landscape. The x-axis represents the choice variable; the function to be maximised is "hard" in that it has discontinuities and multiple local maxima—it is taken from an example given by Holland (1992). The "static" genetic algorithm efficiently samples points from the set of possible choices. In the "strategic" problem, there are two independent choice variables, and each is represented on an axis. The two zig-zagged lines should be read as representing pay-off maxima for one agent keeping fixed the behaviour of the other agent. For a given agent 1 strategy choice (x-axis position), agent 2's genetic algorithm searches for a good solution (point on the solid line); the good solutions are represented on the diagram as the lines of "best responses" to every agent 1 choice. And for every choice by the agent 2 GA, agent 1's genetic algorithm searches for a "good response". Pure strategy Nash equilibria occur when each player is bidding a best response to the other—that is, where the best-response functions cross. Co-evolution arises from the repetition and interaction of these steps. The relation between co-evolution, Cournot dynamics and fictitious play dynamics of textbook economics (for example [Binmore 1992, Chapter 9]) is very close: in the Cournot dynamic, you pick a strategy to start, then play best responses until you reach a resting point (if ever)—these are shown as "NE" points in the example; in the co-evolutionary dynamic, you pick a point and play responses in (approximately) proportion to their past success.
always seem in danger of disappearing into a recursion because for agent A to do best, it must know what agent B will do. Simultaneously, agent B needs to know what agent A will do before deciding what to do. Fictitious play is just one way of thinking our way out of such a recursion; it is a sort of step by step approach that says—"Let the first agent optimise behaviour keeping the other agents' behaviour as if that were a fixed element of the environment; let all agents do this in turn".

Fictitious play dynamics have been investigated by game theorists (see Fudenberg and Levine (1998) for an overview), especially for cases where the strategy spaces are small and easily knowable (and where there is only learning about others' behaviour). Fudenberg and Levine mention the genetic algorithm (Fudenberg and Levine (1998, Section 4.9)) as a candidate learner in cases where the strategy space is large.\(^{21}\) In Curzon Price (1997) and Curzon Price (1999), each agent is represented as a genetic algorithm; the genetic algorithm codes for strategies; a "market simulation" represents the fixed parts of the world ("physics", engineering parameters ...) and the rules determining the outcome of tournaments; these tournaments are played between strategies picked from different firms; the outcomes in the market simulation determine strategy payoffs; every so often, these payoffs are used to "update" each agent's strategies using the genetic algorithm dynamics (crossover and mutation, with associated parameters).\(^{22}\)

\(^{21}\) Fudenberg and Levine (1998) offer criticism of the use of "social learning" GAs in strategic modeling.

\(^{22}\) These models are models of private as opposed to social learning. Whereas the distinction is now well understood (see Vriend (1998) for a discussion), it was not always so at the time of Curzon Price (1997). For example, Marks and Schnabl (1999) contains a public learning GA contrasted to a private learning neural net. The authors do not differentiate effects due to the algorithm and those due to the learning environment; they
This structure is intended to be a reduced form for some of the strategic learning that occurs within firms: the firm is like a GA; within the firm, many strategies are "up for consideration." The firm regularly generates new strategic possibilities; the board or the pricing committee selects strategies in proportion to their past scores (or by chance, if they have never been used). A selected strategy is then tested in the market. This means that it needs to do well relative to the strategies employed within other firms, and not within its own firm. Each firm is thought of as conducting this process, so co-evolution is about the strategies of one firm affecting the payoffs to the strategies of the other firm.

The correspondence between learning in the firm and learning in a GA population is clearly very rough. Maybe the most troubling approximation is that firms typically do not have actual performance data on most of the strategies that they select for trial. Instead, they rely on counterfactual reasoning, inference, theory, gut instinct, consultants' reports, bankers' advice and much more... If a firm is strategically astute, it will even have its own model of how other firms have modeled it... A challenging extension of the simple GA models used here would be the inclusion of a model of the evolution...attribute all differences to the learning algorithm.

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23Why not model these interior processes explicitly, rather than rely on the crude reduced form offered by the GA? Ideally, we would want to model within the firm, and within each agent, and even within each conflicting "will" of each agent... Stopping the modeling at some point is an entirely pragmatic decision—project timetable, feasibility, computing resources.

24The fact that a firm may have models of how other players have modeled its representation of the strategic environment is a version of the familiar game theoretic recursion of "my best choice depends on your best choice, depends on my best choice... " An indication of the practical significance to management of strategic effects relating to perceptions of the firm's model of the environment is the effort that many companies devote to offering industry and market trend analysis for public consumption. In these exercises, firms are saying "this is how we see the environment".
tion of firms' perceptions of their environment to be used to assess candidate strategies.

5.2.5 Results

Curzon Price (1997) tests the GA on a number of simple economic settings, like Bertrand competition, Cournot competition and serial monopoly. Standard Nash equilibria are found with little difficulty. The closest analytical models to the co-evolving GA\textsuperscript{23} predict convergence to Nash equilibrium in these games. The only difference between the analytical models and the co-evolutionary GA is the very large discrete strategy space that is partially (and in these experiments, efficiently) explored by the GA.\textsuperscript{26}

Curzon Price (1997) goes on to describe a set of experiments that are closer to the spirit of an ideal Economic-CAD system. A uniform-price inverse multi-unit auction is modeled that is intended to represent important aspects of the UK's power trading arrangements. The simulation represents the supply-demand matching software used by the electricity Pool, together with a representation of (inelastic) day-ahead demand; the agents are the generators and the strategies being tried and selected are prices (or in some cases prices and quantities). These simulations are inspired by the Fehr and

\textsuperscript{23}In particular, "Exponential Fictitious Play" as described by Fudenberg and Levine (1998, Section 4.9). "Exponential Fictitious Play" seems a closer analogue to the GA's operations than simple Cournot Dynamics because it allows for changing probability weights being attached to strategies depending on past performance. Simple Cournot dynamics are deterministic in the strategy adopted against any other strategy.

\textsuperscript{26}It is possible to make the genetic algorithm behave differently from the standard models of learning. For example, the genetic algorithm has often been used to model a public learning process (see, for example, Arivofic (1996)), in which the updating rules of the genetic algorithm are themselves meant to replicate some element of information exchange in the economy. In these applications, the genetic algorithm is not being used as a learning-agent, but as a sort of reduced form for diverse processes in the economy.
Harbord (1993) model described in Section 5.2.3. The simplest case considered is one in which there are two asymmetric pure-strategy Nash equilibria (it is best for one agent to be doing what the other is not), and at least one mixed strategy Nash equilibrium. At a first level of simplification, this market is modeled by assuming that neither of two producers has sufficient capacity to satisfy market demand, but that both together have more than enough. Therefore, if the two producers bid different prices for their output, the higher priced producer manages to sell less than his full capacity, whilst the lower priced producer sells his full capacity at the high price. It is assumed that in the case of a tie, the market is shared equally, and that there is a maximum price beyond which demand is zero. The market is shown schematically in Figure 5.2.

The genetic algorithm is regularly attracted to one of the two pure-strategy Nash equilibria, in which one agent bids low enough to make it preferable for the other to bid high rather than undercut. The degree of convergence to the pure strategy Nash equilibria can be seen in the fact that close to 100% of the strategies within each population were coding for the strategy, making it very unlikely that anything but these equilibrium pairs would be played in the tournaments.

In Curzon Price (1997) each agent genetic algorithm was parametrised to determine how under-performing strategies were selected for elimination, and new strategies generated. These are versions of the standard “breeding” and “survival” parameters in GAs. These parameters are closely related to the “rate of learning or reinforcement” parameters in other evolutionary learning models. In the simple electricity game, if selection was “slow” – only a small
In the high demand case (with demand at \( Q \) high), the two players, neither of whom has enough capacity to satisfy the entire market, are torn between setting a high price and selling a large quantity. Each wants the other to "do the price setting work". This contrasts with the standard Bertrand competition case: when demand is \( Q \) low, setting a high price means selling nothing at all.
proportion of the best performing strategies were involved in producing new
strategies – then pure strategies are not attained (that is, a heterogenous
population persists). At faster selection rates, the pure strategies emerge,
and at very high selection rates, the populations can co-evolve into an under­
performing state of “lock-in”.27

The simple version of the von der Fehr and Harbord (1993) model tells us
that when players’ capacity is in a certain relation to demand, the electricity
auction produces monopoly prices. The industry was privatised with an
ownership structure that placed National Power and Powergen in such a
relation to each other and to demand much of the time. Economic critics like
von der Fehr and Harbord (1993) and Green and Newbery (1992) suggested
splitting capacity between a larger number of players. Before doing so, the
question of how capacity choice might evolve should be considered: the break­
up of a set of dominant firms may not be an attractive policy solution if there
are strong incentives for concentration to rise again. Thus, endogenising the
choice of capacity levels is an obvious extension of the model.28 The GA
simulation was modified to include a small fixed cost that was paid regardless

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27 Curzon Price (1997) interprets the breeding parameters as representing the continuum between single-mindedness and indecisiveness. Under single-mindedness, a small positive feedback (or “response”, or “assessment”) is followed by a large strategy commitment; depending on the game and other agents’ parametrisation, this can lead outcomes away from Nash equilibrium. Under indecisiveness, feedbacks are so slight that they are overwhelmed by spurious correlations due to noise. Management theorists like both to counsel commitment (“single mindedness”) and nimbleness (“slow selection”). By tuning the GA parameters, we see that there is in fact a trade-off operating: too much sensitivity to the environment can create instability, whilst too inflexible a commitment to a strategy may lead to suboptimal behaviour.

28 Models of capacity choice followed by price competition have been extensively studied. Analysis of Bertrand Edgeworth models include Kreps and Scheinkman (1983) and Fehr and Harbord (1997), who consider a very detailed case that raises some of the issues specific to electricity sector investment.
of realised supply levels, but had to be paid at a certain rate to be capable of selling at all.\textsuperscript{29}

Figure 5.3 shows how the agent populations evolved in the case with fixed entry costs.\textsuperscript{30} The low bidder offers the highest possible quantity minus an increment, and the high bidder offers just one increment of capacity. This is a Nash equilibrium: if I bid low but supply less than the full market (minus one increment), I can increase my market share and profits simply by committing a larger slice of capital; thus supplying anything less than the full market (minus one increment) is not an equilibrium. Supplying any more is not, since I then become the (low) price setter. Finally, there is always a price low enough for the other to prefer to set the high price.

The game is a relatively minor extension of one of the cases considered by Fehr and Harbord (1993). The game shows that the existence of fixed (that is, capacity related) costs may lead to highly asymmetric pre-auction capacity commitments by firms. Moreover, the result shows that there is a relatively simple learning dynamic that does indeed lead to these outcomes in the simulated environment. It is an advance to have been able to delegate to the GA the task of finding equilibria. In these sorts of cases, the advantage of a GA (or other learner) over simply computing a payoff matrix and looking for pure equilibria in the usual way are two-fold:

\textsuperscript{29}The details of the simulation are given in Curzon Price (1997). One interpretation given to this cost is the option fee a firm must pay to have the right to participate in the day-ahead market. Thus, it need not be a capital cost, but rather the fixed cost of having a shift available regardless of the outcome of the auction. It is important for the analysis that capacity commitment can be made day-by-day in the power market, and does not need to be made through slow-moving capital building or divestiture programs.

\textsuperscript{30}These simulations were repeated a number of times with different random seeds. The results were all qualititatively similar to this one. An appendix to Curzon Price (1997) provides details.
Figure 5.3: Evolution of agent strategies in pool game with capacity costs. Lines show the modal values of each variable in each population. By the final generations, these modal values are common to over 90% of the population.
1. It may be *computationally* more efficient when the strategy space is large;

2. The equilibrium has been selected as a stable point of a dynamic adjustment process, thus adding to the plausibility of the prediction (given the plausibility of the chosen dynamic as a representation of learning).

Investigation of the model reveals that it has selected one of a number of non-equivalent pure-strategy equilibria of the game. Table 5.5 shows the payoff matrix for a game of equivalent structure, but made more manageable by trimming down the strategy space to only three capacity commitment possibilities and only three spot price options. The table shows that there are multiple and non-equivalent pure-strategy Nash equilibria of this game. The GA repeatedly, under a range of starting conditions, selected the one shown (or its symmetrical equivalent).

The selected equilibrium is at one of the extreme points of the set of equilibria. Equilibrium multiplicity is so common that equilibrium selection becomes a critical aspect of applied modeling. Lucas and Taylor (1993), in a very detailed model of the England and Wales pool consider a very similar case to argue for the selection of a symmetric payoff mixed-strategy equilibrium rather than a very unequal-payoff pure-strategy equilibrium. Their argument relies on the motivations of managers whose remuneration is part dependent on relative stock market valuations. The small firm in the extreme asymmetric equilibrium has a small capitalisation, and their board are thought to compare them unfavourably with the larger player. In other

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31 Appendix D shows the Mathematica model that was used to compute the payoffs and the Nash equilibria of this game.
words, Lucas and Taylor offer an industry-specific reason for not selecting the equilibrium chosen by the model here. The lesson of the comparison of the results of Curzon Price (1997) and Lucas and Taylor (1993) is that where equilibrium selection is an issue, one needs to think hard about the non-modeled factors that may in fact determine which equilibrium is selected.

This becomes a lesson about sufficiently exploring the relevant model space and parameter space to identify the possible equilibria.\textsuperscript{32}

\begin{table}[h]
\centering
\begin{tabular}{c|ccc|ccc|ccc}
 & $k_l p_l$ & $k_l p_m$ & $k_l p_h$ & $k_m p_l$ & $k_m p_m$ & $k_m p_h$ & $k_h p_l$ & $k_h p_m$ & $k_h p_h$ \\
\hline
$k_l p_l$ & -1 & 0 & 1.5 & -1 & 0 & 1.5 & -1 & 0 & 1.5 \\
k_l p_m & 0 & 0 & 1.5 & 0 & 0 & 1.5 & 0 & 0 & 1.5 \\
k_l p_h & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 \\
& & & & & & & & & \\
k_m p_l & -2 & -2 & 3 & -2 & -2 & 3 & -2 & -2 & 3 \\
k_m p_m & 0 & 0 & 3 & 0 & 0 & 3 & 0 & 0 & 3 \\
k_m p_h & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\
& & & & & & & & & \\
k_h p_l & -3 & 0 & 4.5 & -3 & 0 & 4.5 & -3 & 0 & 4.5 \\
k_h p_m & 0 & 0 & 4.5 & 0 & 0 & 4.5 & 0 & 0 & 4.5 \\
k_h p_h & 4.5 & 4.5 & 4.5 & 4.5 & 4.5 & 4.5 & 4.5 & 4.5 & 4.5 \\
\end{tabular}
\caption{Payoff matrix for the simultaneous capacity and pool game. The strategies involve combinations of capital commitment ($k$) and spot price behaviour ($p$). The subscripts $l, m, h$ stand for low, medium and high. The payoffs shown are for the row player; the players are identical, so column's payoff to row's move $r_i$, column $c_j$, $(r_i, c_j)$, can be found at $(r_j, c_i)$. The pure-strategy Nash equilibria that were not selected in the genetic algorithm runs are shown in italics, and the equilibrium selected in bold. The details of the numerical example are available as a Mathematica notebook from the author, and is reprinted also as Appendix D.}
\end{table}

\textsuperscript{32}Asymmetric capacity equilibria have not, in fact, been selected in the England and Wales Pool: generator market shares have slowly become more equal over time, not less equal. This is an indication that the model was in at least some respects representationally deficient, although it was coherent.
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5.3 GAs for Market Design: Pool versus Medical Intern Experiments

A last set of experiments is described in Curzon Price (1999) that extend the complexity of the simulated environment. As described in Chapter 3, Wolak and Patrick (1997) performed an extensive statistical investigation of the England and Wales electricity market. The authors conjecture that generators are using a strategy of withholding capacity in particular periods to increase price. They tell a complicated story to justify the conjecture, noting that it is probably too complex for analytical treatment. They perform statistical tests on market data to try to validate the conjecture. The hope expressed in Curzon Price (1999) is that this environment would be a good one for agent-based market design: how might market rules or restructuring help to limit market power? A similar hope is expressed in Bunn and Oliveira (2001).

Curzon Price (1999) and Bunn and Oliveira (2001) are both ultimately relatively unsuccessful in building a persuasive case for any market reform. This section will examine how these models fail to be persuasive, and will contrast them with the work of Unver (2001), where a GA based simulation is persuasively explanatory of market structure. The comparison leads to the

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33I have a number of a priori reservations about the conjecture, as well as difficulties with the empirical test, described in Chapter 3.

34 One test of success for a market design model is to be used "in anger" during the market design process itself. When investigating a challenge to the regulator's authority in the recent market re-design process, the UK Monopolies and Mergers Commission (MMC) carefully considered the use of modeling work based on Bunn and Oliveira (2001) in defence of the regulator. The MMC decided not to use these models in justifying its final case. The MMC does not, unfortunately, provide access to internal deliberations as to why they made this decision.
conclusion that the relative failures of the GA-based models of the UK pool are not intrinsic to the modeling method, and that further careful work in this area may very well produce better results.

5.3.1 Representational Realism in Pool Simulations

Curzon Price (1999) and Bunn and Oliveira (2001) aim for representational realism in their electricity market simulations. Curzon Price (1999) extends the results summarised in Section 5.2.4 for the case in which bids represent a multi-period commitment to a supply schedule, where demand can vary period-by-period. This is the context which in Fehr and Harbord (1993)'s analysis allows only mixed strategy equilibria, and which these authors argue is often the relevant regime for an analysis of the UK Pool. Looking back to Figure 5.2, the problem addressed is the following: given that "Q High" occurs with some probability, and that "Q Low" occurs with some probability, and that only one price bid can be chosen, then what is the best strategy? In other words, the price announced is a commitment in the sense that it cannot be tailored to every level of demand that occurs.

The GA model in Curzon Price (1999) discovered no pure-strategy equilibria. The result is shown graphically in Figure 5.4, where it is compared to a "close" explicit solution to the problem. The largest number of discrete prices for which mixed strategies were explicitly computed\(^{35}\) was six; the co-GA selected over 64 strategies.\(^{36}\) The figures show that the two

\(^{35}\)The mixed strategy algorithm was computed by the Dickhaut and Kaplan algorithm (Dickhaut and Kaplan 1992) (Varian 1992).

\(^{36}\)It is close only in the sense of being a similar, but smaller, problem that was explicitly solvable. I have no metric of how close one might expect the solutions of the two problems to be.
linked populations of the genetic algorithm do not settle onto any distribution. It is also (just) visible from examination of the "close" solution in the top rows of the diagrams that the cycles encompass the close solution.$^{37}$

Cycling in stochastic learning algorithms is known (see, for example, Posch (1997) and Erev and Roth (1998)). In fact, one might expect mixed equilibria to manifest themselves as cycling. So the GA's behaviour is unsurprising, although cycling could be caused by much else, for example integer constraints.$^{38}$

The discovery of these cycling solutions, and their apparent lack of relatedness to the theoretical results of Fehr and Harbord (1993) led to the unnecessarily pessimistic conclusions of Curzon Price (1999). It is argued there that the lack of theoretical backing and the lack of empirical support for the parameters of the learning model should lead to a scaling-back of ambitions for learning agent simulations in market design, and that more intellectual effort should be devoted to exploring the psychological foundations of learning in economic contexts.

This conclusion seemed to be confirmed by the limited success of Bunn and Oliveira (2001) (and the related study submitted to the Monopolies and

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$^{37}$An animation of the results (available from the author) shows the two distributions cycling around the "close" distribution.

$^{38}$One of the mechanisms that generates cycles in the genetic algorithm is simply a function of the coding rule chosen. If the strategy representation is such that the mixed-strategy is not closed under the reproduction operator (assuming no mutation), then the genetic algorithm cannot but "expel itself" from the mixed equilibrium. But if for each mixing distribution one can find a reproduction operator and a coding scheme such that the distribution is closed under reproduction, the genetic algorithm will stay at the equilibrium distribution if it ever gets there. Note that under this view, the trial and error algorithm searches over strategies and encodings and "novelty generators". Simple genetic algorithm applications fix the last two of these arbitrarily, and without first settling the question of the interrelationships of the three.
Mergers Commission (see footnote 34)). In both these models, the degree of representational realism is increased beyond that of Curzon Price (1999), and the collection of reforms of the market rules known as the “New Electricity Trading Arrangements” (NETA) is analysed. In both papers, the authors claim to discover something about the market reforms without providing strong reasons for rejecting the belief that they are discovering some merely incidental features of the learning algorithm used. Two examples of this difficulty are taken.

When Bower and Bunn (2000) find cycling behaviour in their output, the authors take average values of prices over the cycle, as if agents were mixing over strategies. As mentioned already, these cycles may be generated by the detailed interactions of the reinforcement learner and the environment, and the periods of the cycles are related to the rate of learning. So comparisons of average prices over cycles between two designs rely heavily on the detailed parametrisation of the learner. As discussed below, Unver (2001) offers an independent source of parametrisation for the GA via laboratory experiments, but neither Bower and Bunn (2000) nor Curzon Price (1999) do so. We therefore have little confidence that the differences reported are genuinely differences that arise from market design.

A similar difficulty is apparent in Bunn and Oliveira (2001). The authors report a Uniform auction experiment with a very similar environment to the pool experiments of Curzon Price (1997). While the latter report that the GA converges onto the sorts of “High/Low Price” equilibria described in Fehr and Harbord (1993), the former report that this “collusive” regime is avoided. The two models are using slightly different reinforcement learners in slightly
Figure 5.4: Cumulative frequency distributions of the 2 genetic algorithm populations under the fixed commitment pool game. The horizontal axis shows price, and movement along the vertical axis is development over generations. The generations are started at 340, and each increment is 5 generations. Lighter shades are greater frequencies. The shade for each price, at each generation, provides an indication of the probability of the "player" selecting a lower price. In both figures, the top row is composed of the explicitly solved mixed-strategy equilibrium. The jagged nature of the actual development of frequencies is a reflection of the cycling distributions.
different environments, and generate a significantly different conclusion.

In such cases, where we appear to have great model sensitivity of results, effort needs to be expended to justify particular modeling choices. Neither papers attempt a serious justification of parameter values or learning algorithm choices. In Bunn and Oliveira (2001), agents are allowed to make only incremental changes to previous period strategies. This may make it difficult for the learner to explore the payoffs to strategies that require highly asymmetric bids, as are required in the equilibria identified by Fehr and Harbord (1993). Incrementalism in learning may be a sensible restriction, but it needs to be supported empirically. The agent-based studies of the UK Pool surveyed here are ultimately unsatisfactory because of insufficient independent validation of the outcomes.

In contrast to Bunn and Oliveira (2001), Nicolaisen, Petrov and Tesfatsion (2001) model a generic electricity market and make suitably generic predictions about bidding behaviour and market power under discriminatory auctions. They model an electricity market as a discriminatory double auction (that is, one in which both buyers and sellers are able to bid). The authors find high levels of efficiency, a result which is robust to changes in the learning algorithm. They simulate the market under a wide range

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39 For example, Bunn and Oliveira (2001) model several time periods over which demand varies; if the changes in bidding regime occur frequently, then the incrementalism of the learner may hinder the emergence of strategies that require large shifts in behaviour.

40 This result is consistent with the experimental result of Chapter 4: Nicolaisen et al. (2001) do not run a discriminatory versus uniform comparison, and Chapter 4 reports high levels of efficiency for both formats, albeit higher ones for uniform auctions. The authors compare their result to Gode and Sunder (1993), arguing that the two results are similar. However, it is important to note that the efficiency of the Nicolaisen et al. (2001) result arises from agent learning, not random bids. Gode and Sunder (1993) is described in greater detail in Appendix A.
of capacities and ownership concentrations, and conclude that popular measures of market power based on market aggregates are poor predictors of the exercise of market power. Theirs is a persuasive example of a learning agent simulation used to counter faulty intuitions.\footnote{Nicolaisen et al. (2001) do not claim to be representational of any particular electricity market. They use moderately elastic demand curves for electricity, which are not typical of the UK market, as discussed on page 156. For their model to be used in prescriptive settings, one would want to repeat it with parameter values relevant to the market in question.}

A striking contrast to the agent-based model of the UK pool is the analysis in Unver (2001) of the regional markets for medical interns in Britain. The author uses an agent-based model to provide a persuasive account of the survival of some allocation schemes and not others, in a setting where traditional game theory had been unable to mark a distinction. Linear Programming allocation schemes for medical interns to hospital places are found to be stable in practice—they have been in operation in some UK regions for over 30 years—but unstable in theory, in that optimal behaviour predicts "unravelling" of the market, with a race to ever-earlier and information-poorer contracting. "Shapley" schemes are stable both in practice and in theory, while other mechanism have proven to be unstable in practice and unstable in theory. The mysterious cases are the Linear Programming methods. Unver (2001) shows that a GA distinguishes correctly between the three types of scheme.

Unver (2001)’s model is summarised below.

**Market** The matching market for medical interns in the UK, whereby medical students are matched to hospitals by some mechanism that relates students’ and hospitals’ preference orderings.
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Equilibrium Selection is performed by private learning Genetic Algorithm.

Agents are hospitals and students; the simulations are run with six of each. Hospitals and student can be either “productive” or “non-productive” with probability 1/2. Hospitals prefer productive students, and students prefer productive hospitals. The degrees of preference for specific agents are randomly generated. The evolutionary analogy is argued to be appropriate because students learn from previous generations of students how to behave in the matching markets, while hospitals learn from year to year which strategies work for them.

Strategies The matching games map player preferences onto matching results. The GA strategy strings represent each agent’s preferences and behaviour in each stage of each matching game. Instability occurs when a matching in one period is undone in a later period.

Treatments The simulations are run for different matching mechanisms: decentralised; centralised with deferred acceptance (Shapley mechanisms); centralised with matching by linear programming under both deferred and binding contract schemes; mixed treatments, where two early periods are decentralised and a final period uses a centralised scheme. All simulations are of a three period model.

Simulation Parameters Extensive sensitivity analysis to parameters is performed. The mutation and crossover probabilities are selected so that the dynamic path of key aggregates appears qualitatively similar to the evolution of the same aggregates in an analogous, prior laboratory
experiment. Each GA simulation is run thirty times, with different random seeds, and each of those runs is 160 generations.\textsuperscript{42}

Unver (2001) generates conclusions regarding the stability and efficiency of mechanisms, and the results are mostly found to be robust to changes in the GA parameters.

In the context of this Chapter's discussion of model validation, it is interesting to examine Unver (2001)'s use of data to support the conclusion. He uses four classes of empirical validation:

1. data from laboratory experiments to calibrate aggregate properties of the GA outputs;

2. anecdotal data to suggest that the GA is adequately representational of the way that real strategies might be updated between cohorts of students and consultants in hospitals;

3. sensitivity analysis on different starting points and random number sequences;

4. data relating to the existence of the institutions under study: the historical stability of the LP schemes is taken as suggestive that an evolutionary/learning process is operating, since such a dynamic predicts the stability of such schemes.

The combination of these four validation strategies makes the explanation of why the LP schemes are stable to be strongly persuasive.

\textsuperscript{42}The agent strategy populations are quite small—7 per agent type, compared to 100 strategies per agent in Curzon Price (1997)—because of the complexity of each strategy and the computational resources required to perform each simulation.
How would the analysis change if the task were to recommend an allocation scheme rather than explain the persistence of allocation schemes—in other words, if the question were one of market design? Only the last type of evidence would be unavailable—the others would remain as powerful as before. One can imagine that the LP schemes had never been tried, but that a GA simulation had discovered them to be stable. This could be a useful market design discovery, and empirical emphasis would be placed, in order to compensate for the lack of "institutional evidence", on deepening the support from experimental data, from sensitivity analysis and from the representativeness of the GA.

The concern, in market design mode, is that there may be "in practice" unstable schemes that are found to be stable in the GA simulation: we do not know that the set of stable schemes in practice is the same as the set of schemes stable under the correctly parametrised GA, although the Unver (2001) analysis points to some encouraging overlap.\footnote{Unver (2001) sensibly suggests the possibility of considering a given game under a wide variety of evolutionary dynamics—that is, performing not just sensitivities of GA parameters, but sensitivities to evolutionary algorithms.}

### 5.4 Conclusion

This chapter has reviewed a range of modeling styles in the context of seeking appropriate tools for market design in the UK electricity market. The "applied theory" models, such as Fehr and Harbord (1993), were found to yield strong conclusions, but at the cost of strong rationality assumptions and a limited representation of the strategic environment. The econometric simu-
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lation, represented by Green and Newbery (1992), suffers similar drawbacks, in this case compounded by the need for arbitrary equilibrium selection. The limitation of these traditional approaches leads to the consideration of agent-based models, such as those of Curzon Price (1997), Curzon Price (1999), and Bunn and Oliveira (2001). These models attempt to be both representational and prescriptive of the UK pool. However, the authors do not succeed in persuasively establishing that their simulation results reflect properties of the systems they are simulating rather than the specific modeling choices they have made. This is in contrast to the agent-based modeling of Unver (2001), which uses a combination of institutional and experimental data to be persuasively explanatory.

Unver (2001)'s success suggest that a useful direction for agent-based models in the context of market design would be to try to automatically generate and test a large number of possible mechanisms. This would allow one to build a whole set of designs that are predicted by the simulation to be stable, or efficient, or revenue enhancing, and these would become candidates for further investigation, using other empirical methods. An agent-based model that could search over mechanisms would be successful to the extent that it reproduced important aspects of known mechanisms, while generating promising new candidate mechanisms.

Consideration of Unver (2001) provides some lessons for future agent-based modeling of the UK power pool. To some degree, the success of the analysis derives from choosing a very "clean" case to study: the theory of matching is well-developed and makes clear, and often successful predictions. There is considerable empirical analysis, both of field data and laboratory
data. All of these prior analyses inform Unver (2001)'s agent-based modeling choices to some degree.

In this light, the general problem of modeling the UK pool appears to be too large given the current level of understanding of the market. The theoretical results are limited, the field data interpretations are contested, and there are no serious experimental studies of the market. A way forward for agent modeling of the pool would be to start with a subset of the data, identifying one or a few clear bidding anomalies. These anomalies would be like the "stable in fact but not in theory" LP matching institutions. A combination of careful examination of the field data, laboratory work and agent modeling might succeed in replicating for a small part of the UK power market the success of Unver (2001). The introduction to this thesis ended with a statement of support for methodological diversity. Unver (2001)'s success, arising in a field excellently served by the whole range of microeconomic methods, brings this thesis to a close with the same message: modeling advances will be accompanied by methodological diversity.

\*\*\*A good number of anomalies are collected in Brealey and Lapuerta (1998). One particularly intriguing result reported is that for an initial period of a few months after a reduction in the ownership concentration, generator (supplier) bids actually increased.\*\*\*
Appendix A

Zero-Intelligence Benchmarking

A.1 The Zero Intelligence Benchmark

A.1.1 Introduction

This appendix considers the effectiveness of the tested auction mechanism when compared to random benchmarks. It models a slightly simpler mechanism than the one tested in laboratory—the analysis is restricted to two players, and their choice set is somewhat reduced compared to the experimental setting. This simplified setting is sufficient to establish two points:

1. that the random, or “zero intelligence” benchmark accepts a wide range of interpretations;

2. that under what is argued to be a preferred interpretation of random bidding, the “zero intelligence” bidders perform poorly compared to
the human subjects.

This last point is at odds with Gode and Sunder (1993), who use a "Zero Intelligence" (ZI) benchmark to establish that the institution of the double auction has a larger role to play in high efficiency outcomes than do the efforts of human subjects. The difference between the two conclusions comes from our choice of an empirical ZI benchmark, as opposed to Gode and Sunder (1993), who adopt an a priori benchmark.

Gode and Sunder (1993)'s interest in the ZI benchmark stems from the thought that if economic surplus can be achieved by Zero Intelligence agents constrained by rules representing the market institution, then we can properly say that the institution has performed economic work. Moreover, the incremental performance of intelligent subjects above ZI subjects becomes a natural measure of the economic work performed by subjects' own efforts. Gode and Sunder (1993) put it thus:

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\ldots \text{in the experimental economics literature, the percentage of the maximum possible surplus extracted has often been used as an index of learning and rationality and of the control attained in an experimental economy. Such inference may not be appropriate for market mechanisms that yield all their surplus to Zero Intelligence (ZI) traders.}\]

The ZI benchmark is thus an interesting analytical construction. A pragmatic interpretation of it is that in market design problems, we might con-

\footnote{It should be noted that in the statistical analysis of Chapter 4.1, we do not use the level of surplus attained to measure the amount of learning, although we do take changes in this level to track learning.}
sider ZI mechanisms as candidates for allocations of goods. A market
designer might want to add ZI mechanisms to the set of mechanisms to
be considered: they have obvious advantages of cost, simplicity and non-
manipulability.

A.1.2 Choosing a ZI Benchmark

There is no single ZI benchmark for an allocation process—each measure
requires careful consideration of the appropriate benchmark. We have com­
pared the following possibilities:

A simple binomial distribution of goods (called "binomial" below), whereby
each unit of supply is randomly assigned to a player. This is the "low­
est intelligence" scheme: it requires for implementation only a random
device, memory for counting, and a control mechanism for stopping.

Random bids, constrained by the "experimental box" (called "ZI-box"
below) ZI bidders submit random bids whose only constraints are to
lie within the price and quantity axes of the experiment.

Bids randomly constructed but satisfying a 1-shot budget constraint
(called "ZI-G-S" below) is the Gode and Sunder (1993) ZI benchmark.

The ZI bidder's intelligence is restricted to never offering to pay any

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2Some goods are allocated by ZI lottery: "Green Cards" in the USA and it has been
suggested that "People's Peers" in the UK might also be chosen randomly.
3Experiments were conducted to investigate the effect of the method of random bid
generation. In particular, one can think of creating "allowable" (i.e. downward sloping)
random bids by construction or by rejection sampling. Both methods were tried. While
they do not yield identical results, the differences are small enough when compared to
the other effects being considered to concentrate on bids that were random by construc­
tion. Rejection sampling requires significantly greater computational resources in large
bid spaces.
more than a good is worth to him—his bids are always within his valuation curve.  

Bids randomly constructed but satisfying an empirical 1-shot constraint

(called “ZI-Empirical” below) It was found in the experiments of Chapter 4.1 that many human subject bids did not in fact always satisfy the Gode and Sunder (1993) ZI constraint. This suggests that the constraint is too strong to be taken to be literally “Zero Intelligence”. The human-subject experimental data was used to determine the maximum violation of the 1-shot budget constraint that had in fact been observed. This was picked as a lower bound on the 1-shot constraint that humans can be taken to satisfy, and therefore as an appropriate starting point for ZI bid constraint.

The experimental, human-subject, bids The result of the human experiments were reported in a comparable efficiency measure to the one used for the ZI simulations. The ZI simulations were sufficiently different from the experimental conditions for direct comparison to be difficult. Nevertheless, the normalised experimental result is interestingly similar to that reported in Gode and Sunder (1993).

---

4The ZI bidder under this scheme needs to know the human subject’s valuation function; it is therefore not a practical ZI scheme as far as market design goes, although it continues to be interesting analytically.
5Gode and Sunder (1993) themselves do not report whether their human subjects violated their ZI constraint.
6Enron was a prominent player in the UK gas market to which these experiments related; they have shown by their catastrophic bankruptcy that sophisticated bidders can find it hard to satisfy apparently simple budget constraints.
A.1.3 Constructing an empirical ZI benchmark

The subjects in the human experiments performed a significant amount of "over-bidding"—they quite often offered to buy at prices which could have lost them money on a given unit. 8.21% of all bid points in the discriminatory auction without secondary market were outside the value curve, and 24% of all bid points in the uniform without secondary market were outside the value curve. To call this "over-bidding" is already to have a particular theory of optimal behaviour in mind. The subject may in fact have been bidding intelligently—trying to signal intentions, making use of repeated game strategies, or simply applying to the laboratory cubicle behaviour patterns that work well in other settings.\(^7\)

Regardless of the reasons for these bidding patterns, humans behaved in ways which would have been disallowed by Gode and Sunder (1993)'s ZI bidders.\(^8\) We do not want the ZI benchmark to be more restrictive than the behaviour exhibited by humans—this would make a nonsense of its claim of measuring a Zero Intelligence point.

The empirical approach adopted here was to seek a lower bound for the ZI constraint by taking the actual observed over-bidding maximum as the ZI constraint. This constraint says: "A ZI bidder cannot be more constrained than this, or else it would reject observed human behaviour." This is a bound in the sense that our sample of the extreme cases of over-bidding may not be

\(^7\)For example, "over-bidding" might be the result of bidders wanting to buy units of the good for the sake of owning quantity, regardless of its profitability.

\(^8\) Gode and Sunder (1993) consider the case of a repeated double auction rather than a simultaneous multiple unit auction. The translation between the two frameworks proposed here, by which bidding above cost/below value on each bid in a double auction equates to bidding within the value curve in the multiple unit auction, seems straightforward.
representative, and much greater levels of it may be sometimes observed.

Figure A.1 shows the bid and the valuation curve that was selected as lower bound for the ZI constraint. The bid came from round 6 of a discriminatory auction without secondary market. This maximum over-bid was expressed in relative terms, as a multiple of the valued quantity bid for at each price, and this over-bidding factor was applied to the simulation environment.

Figure A.1: Maximum observed over-bidding.
APPENDIX A. ZERO INTELLIGENCE BENCHMARKING

A.1.4 Results

Monte Carlo simulation was used to generate bid distributions for the three random-bid ZI benchmarks. Two players with identical valuation functions were allowed to submit bids in a ten by ten space of price and quantity. The gross surplus achieved as a percentage of the maximum possible was measured for all the ZI benchmarks.

The results are represented in Figure A.2. This graph plots the frequency distribution of different relative efficiency levels achieved in the different simulations. We see that "ZI G-S", the closest simulation to Gode and Sunder (1993), does indeed confirm their result that such a scheme achieves a large proportion of the surplus available much of the time.\(^{10}\) However, we see also that "ZI-Empirical", our preferred ZI benchmark, achieves significantly less surplus; in fact, only "ZI-Box", the random construction of bids within the experimental "box" constraint, seems to do worse.

A natural way to think of ranking the amount of allocative work done by the various schemes is to see which has the most frequency mass towards high efficiency. The schemes are ranked according to this measure in Table A.1. We see that "ZI- G-S" does the most work at all efficiency levels; that the "Actual" (human) outcomes are next at the high efficiency end, although at lower efficiencies the binomial and the "ZI - Empirical" do better; we note that the least work throughout is done by the "ZI-box". If we measure

\(^{10}\)We note that the actual observed distribution of surplus is somewhat similar to the "ZI G-S" distribution. This also accords with Gode and Sunder (1993)'s observation. However, in the experiments reported here, there were significant differences between the human and ZI environments, and one would not expect the two to be easily comparable. The comparison is included as a rough point of comparison only.
Figure A.2: Efficiency in the ZI simulations and in the human simulations.

allocative work as being the frequency with which outcomes are in the top bin, we find that the “ZI-G-S scheme” does the most, while our preferred “Empirical” scheme does the least.

<table>
<thead>
<tr>
<th>Efficiency bin, %</th>
<th>96-100</th>
<th>88-95</th>
<th>79-87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Efficient</td>
<td>ZI-G-S</td>
<td>ZI-G-S</td>
<td>ZI-G-S</td>
</tr>
<tr>
<td>Actuals</td>
<td>Actuals</td>
<td>Binomial</td>
<td></td>
</tr>
<tr>
<td>Binomial</td>
<td>Binomial</td>
<td>ZI-Empirical</td>
<td></td>
</tr>
<tr>
<td>ZI-&quot;box&quot;</td>
<td>ZI-Empirical</td>
<td>Actuals</td>
<td></td>
</tr>
</tbody>
</table>
| Least Efficient   | ZI-Empirical| ZI-"box"| ZI-"box"

Table A.1: Efficiency ranking of the ZI benchmarks.
A.1.5 Conclusion

Gode and Sunder (1993) propose "Zero Intelligence" analysis as a method of measuring the work done by an institution as opposed to its participants. The attractiveness for mechanism design is clear: one wants to find institutions that relieve demands on human understanding, or even eliminate the need for human intervention at all. Gode and Sunder (1993) go further to claim that a 1-shot budget constraint in a double auction goes a long way to achieving the amount of allocative work that humans perform in the same context.

We have reproduced results comparable to Gode and Sunder (1993)'s in the context of a multiple unit auction. We find that forcing random bidders to bid within their valuation curve produces allocatively highly efficient outcomes. However, we also found that human subjects often violate this supposedly zero intelligence constraint. This fact led us to look for an empirically based constraint for a ZI benchmark. Using such a constraint, we find that outcomes are significantly less efficient. This benchmark suggests that human intelligence and learning still plays a significant role in achieving the multi-unit auction outcomes observed in the laboratory.

We have not examined the way that "over-bidding" varies by mechanism type. It is possible that Gode and Sunder (1993)'s humans did not themselves violate the 1-shot budget constraint to the degree that the subjects of these experiments did. If so, this might be related to the treatment or to the institution itself. The study of ZI benchmarks suggests that a closer examination of unusual bidding might point to interesting and possibly important differences between mechanisms.
Appendix B

Setting the experimental learning phase

B.1 Setting the Learning Phase

The learning phase was set as being the first four auctions of a session. The determination of the learning phase is in part arbitrary, and reflects the original design limitation that no switching conditions were included to control explicitly for history-dependent effects (see discussion on page 117).

A separate learning period for the "secondary market" condition was not included in the final model. Table B.1 shows regression results that include a learning dummy variable for the first auctions of the secondary market condition. The coefficients are not significant.

An aggregate regression on revenue which includes the number of the round in the non-secondary market condition as an explanatory variable is shown in table B.2. The round variable is found to be highly significant.
APPENDIX B. SETTING THE EXPERIMENTAL LEARNING PHASE

Regression Coefficients, Revenue Equations

<table>
<thead>
<tr>
<th>Dummy Variable</th>
<th>Revenue Coefficient</th>
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</thead>
<tbody>
<tr>
<td>Auction Uniform=1,</td>
<td>-0.13 **</td>
</tr>
<tr>
<td>Type Discriminatory=0</td>
<td>-0.12 **</td>
</tr>
<tr>
<td>Elasticity High=1, Low=0</td>
<td>-0.11 **</td>
</tr>
<tr>
<td>Secondary Present=1, Market Absent=0</td>
<td>-0.33 **</td>
</tr>
<tr>
<td>Learning Present=1, Phase (1) Absent=0</td>
<td>0.18 **</td>
</tr>
<tr>
<td>Learning Present=1, Phase (2) Absent=0</td>
<td>0.03 n</td>
</tr>
</tbody>
</table>

** Significant at 95% level
n not significant at 90%
(1) First 3 auctions of session
(2) First 3 auctions of secondary market

Table B.1: Aggregate regression checking the insignificance of learning in the early rounds of the secondary market.

This regression suggests that some form of learning is occurring throughout the non-secondary market phase of the experiment, as players understand how to shade more effectively (the coefficient on revenue is negative).

Regression Coefficients, Revenue Coefficient

<table>
<thead>
<tr>
<th>Dummy Variable</th>
<th>Revenue Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auction Type Uniform=1, Discriminatory=0</td>
<td>-0.14 **</td>
</tr>
<tr>
<td>Elasticity High=1, Low=0</td>
<td>-0.13 **</td>
</tr>
<tr>
<td>Secondary Present=1, Market Absent=0</td>
<td>-0.33 **</td>
</tr>
<tr>
<td>Learning Phase Indexed, 1-10 for Auction Only</td>
<td>-0.03 **</td>
</tr>
</tbody>
</table>

** Significant at 95% level

Table B.2: A continuous, linear learning rate model.

However, examination of the data over the first 10 rounds—see Figures B.1 and B.2—suggests that the rate of learning is not linear, with greater change in the average level of revenue and efficiency in the early rounds than in the later rounds. This is captured in Figures B.1 and B.2 by fitting a power model relating the round number to the normalised revenue and efficiency values. Figures B.3 and B.4 plot the rate of change of efficiency and
APPENDIX B. SETTING THE EXPERIMENTAL LEARNING PHASE

revenue (as given by the fitted power curve) by round. These figures capture the visual intuition that the first 3 or 4 rounds of play involve a high rate of learning, which thereafter tails off. 4 rounds was chosen as the cut-off, although the analysis was not qualitatively different with a 3 round or a 5 round cut-off.

Figure B.1: Early round revenue: learning in the discriminatory auctions.

Figure B.2: Early round efficiency: learning in the uniform auctions.
Figure B.3: Rate of change of learning in the discriminatory auctions.

Figure B.4: Rate of change of learning in the uniform auctions.
Appendix C

Operation of the Experimental Secondary Market

C.1 Operation of the Experimental Secondary Market

C.1.1 Secondary Market Modeling

The underlying principle in modeling the secondary market was that the gas market bidders in the primary auction would have opportunities to re-trade their portfolio of storage capacity. The major participants in the two markets (except the natural monopoly supplier) are the same, and have the same idiosyncratic valuation of storage in the two markets. The motivation to re-trade in this setting comes from two factors:

- there may be inefficiencies in the primary auction allocation that offer a potential for mutual profit,
• some small “noise” traders were introduced to the secondary market, who might be net sellers or buyers of storage.

The secondary market is thus a “second chance” for players’ sourcing of gas needs. For modeling and experimental convenience, the secondary market was built to be perfect and almost frictionless. An exogenous element of friction was introduced in the form of a 10% discount on all profits made in the secondary market. The perfect, almost frictionless assumption allowed all secondary market trading to be carried out by the software.

The sequence of events in the secondary market condition is as follows:

1. Bidders bid in the primary auction;

2. Bidders are shown the allocations and profits they make in the auction;

3. Secondary market demand curve is constructed by aggregating the true valuations of participants in the primary auction, and adding a random amount of “noise demand” representing up to 5% of the total;

4. Total, inelastic, secondary market supply is set equal to the total allocated in the primary auction, plus some “noise supply” representing up to 5% of the total.\(^1\)

\(^1\)The automatic construction of aggregate demand in this way in effect forces onto bidders a “truthful” bidding strategy in the secondary market.

\(^2\)“Real” traders in UK gas are regulated under the gas transportation license agreement, which is a relatively burdensome license for which few firms qualify. In particular, it is an agreement that binds firms with physical assets in gas supply. A number of parties have an interest in gas price movements who are not in any way involved in gas supply, like large consumers and trading houses. These are the real counterparts of the experiment’s “noise” traders.

\(^3\)This additional supply can be thought of as coming from the suppliers of “virtual storage” contracts, rather than suppliers of physical storage.
APPENDIX C. OPERATION OF THE EXPERIMENTAL SECONDARY MARKET

5. A secondary market price is automatically computed at the intersection of supply and demand;

6. If subjects have unallocated demand at a valuation higher than the secondary market price, the experimental software purchases for them units at that price at a profit equal to the difference between value and price. Alternatively, if subjects have allocated units at a valuation below the secondary market price, they sell units at that price at a unit profit equal to the difference between price and value;

7. Subjects are shown a simulation of these trades on-screen; their net sales and purchases are reported to them, with total discounted and undiscounted profits reported.

Figure C.1 extends the example of Figure 4.1 to demonstrate the modeling of the secondary market. The aggregate bid curve of Figure 4.1 is overlaid with the true value curves of the subjects (marked in light grey). Note that while the bid curves must, by construction, be monotonically decreasing, the corresponding valuations need not be. In the example shown, the valuation on item 5, not allocated in the auction, is higher than the valuation on item 3, which was. There is thus an opportunity for a profitable re-allocation. This is shown, through a uniform price secondary market, in the bottom of Figure C.1. Each subject makes additional profits of 1 unit.

This treatment of the secondary market was judged to be a good first step in modeling the secondary market in gas storage. In particular, both

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4The figure does not demonstrate either the addition of noise traders or the discounting of profits. Noise traders are added as random additions to demand or supply; profits were discounted after all trading had occurred.
APPENDIX C. OPERATION OF THE EXPERIMENTAL SECONDARY MARKET

Figure C.1: Model of the Secondary Market

the auction and the secondary market is dominated by the same few players, all of whose demand depends on the role of gas storage in their own, idiosyncratic, production functions. The largest weakness of the treatment is the almost-frictionless environment, in which all profitable trades are made. The exogenously imposed 10% discount rate cannot be considered to be an adequate model of the market power that could be exercised in the secondary market. All that this discount factor does is to make the market exogenously unattractive. Moving to a more realistic environment for the secondary market is desirable, although difficult: the frictionless market made the automation of the secondary trading particularly straightforward. A more realistic treatment of the secondary market would allow players to exercise market power in the secondary market, for example by withholding purchases made in the auction from secondary market supply. Moreover, in a more realistic setting, one could not expect all profitable trades to be made, simply because
of information asymmetries.

C.1.2 Secondary Markets and Common Values

In the auction literature, the assumption of “Common Values” (CV) is often justified by the existence of resale markets (see, for example, Klemperer (2000)). In the case of private value (PV) auctions, the profit that can be made from auction purchases derives from each subjects' idiosyncratic and exogenous valuation function, whereas in the case of CVs, the profit that can be made from a purchase in the auction depends on the price in a secondary market, which is common to all. For example, the value of an oil lease depends on the value of the oil contained in it, and the (purportedly) competitive spot market for crude oil means that, to a first degree of approximation, no company values a barrel higher than another: “barrels are just dollars”. Auctions with competitive resale markets are therefore typically modeled as Common Value auctions, and these are the settings that give rise to interesting phenomena such as the winner’s cures (see Klemperer (2000)).

Despite a superficial similarity, the secondary market as modeled here does not translate the primary auction into a CV framework. Figure C.2 shows how a valuation function for the primary auction is derived in the case modeled here. The secondary market, represented in the left hand figure, clears at a price of Pm. The idiosyncratic demand of one bidder (light grey) is shown as it contributes to secondary market demand. Note that the three units allocated to this bidder are valued not for the pure monetary sum of Pm, but for their idiosyncratic value as represented in the value curve. Thus,
for those three units, the willingness to pay in the primary auction (ignoring the 10% discount factor) is just the same as in the secondary market, giving the light-grey, downward sloping portion of the valuation curve in the right hand figure. However, the existence of the secondary market, however, does augment the primary auction demand, since the auction becomes an opportunity to buy with a view to resale. In fact, at any price below the secondary market price, the true valuation of the subject should extend to the maximum possible, since any purchase on these terms will generate a profit. This is the common value component introduced by the secondary market, shown in dark grey.

![Figure C.2: Valuations Induced by the Secondary Market](image)

Figure C.2: Valuations Induced by the Secondary Market

The analysis and data presented in Chapter 4 are consistent with the view that the secondary market did not induce a change to CV compatible behaviour in subjects. In other words, a combination of the intrinsic modeling choices made and the experimental set-up seems to have prevented subjects from exploiting the common value component of the secondary market condition.
Appendix D

A Mathematica Model of the Fehr/Harbord game with Capital Commitment
Calculating Nash equilibria of a "Fehr/Harbord" game with fixed costs.

The payoff function.

\[
\text{profits}[\text{ki}_\text{, kj}_\text{, Pri}_\text{, Prj}] := \\
q[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] \\
(\text{PrMkt}[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] - \text{opcost}) - \\
\text{ki CapCost}
\]

The quantity sold in the market; different cases are defined by the "/;" operator.

\[
q[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{ki} /; \text{ki} + \text{kj} \leq \text{dem}; \\
q[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \text{ki} /; \text{Pri} < \text{Prj}; \\
q[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{Max[}\text{dem} - \text{kj}, 0] /; \text{Pri} > \text{Prj}; \\
q[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{dem} / 2 /; \text{Pri} = \text{Prj};
\]

The market price in the corresponding cases.

\[
\text{PrMkt}[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{Max[}\text{Pri}, \text{Prj}] /; \text{ki} + \text{kj} \leq \text{dem}; \\
\text{PrMkt}[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{Pri} /; \text{And[}\text{Pri} < \text{Prj}, \text{ki} > \text{dem}]; \\
\text{PrMkt}[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{Prj} /; \text{And[}\text{Pri} < \text{Prj}, \text{ki} < \text{dem}]; \\
\text{PrMkt}[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{Prj} /; \text{And[}\text{Prj} < \text{Pri}, \text{kj} > \text{dem}]; \\
\text{PrMkt}[\text{Pri}_\text{, Prj}_\text{, dem}_\text{, ki}_\text{, kj}] := \\
\text{Pri} /; \text{And[}\text{Prj} < \text{Pri}, \text{kj} < \text{dem}];
\]

Parameter Values
dem = 2;
vol1 = 10;
opcost = 0;
CapCost = 3;
capacities = {0.5, 1.2, 1.5};
prices = {1, 3, 6};

An example of the "profit" function at work

profits[4, 4, 10, 1]
{12, 32}

Building the table of pay-offs via the looped use of the "profits" function.

Payoffs = Table[
  profits[capacities[[ki]], capacities[[kj]],
  prices[[Pri]], prices[[Prj]]],
  {ki, Length[capacities]},
  {kj, Length[capacities]}, {Pri, Length[prices]},
  {Prj, Length[prices]}];

Picks out i's payoffs

colis[Poscapj__, Pospricej__] :=
  Flatten[Table[profits[
    capacities[[ki]], capacities[[Poscapj]],
    prices[[Pri]], prices[[Pospricej]]],
    {ki, Length[capacities]},
    {Pri, Length[prices]}]]

Picks out j's payoffs

rowis[Poscapi_, Pospricei_] :=
  Flatten[Table[profits[
    capacities[[Poscapi]], capacities[[kj]],
    prices[[Pospricei]], prices[[Prj]]],
    {kj, Length[capacities]},
    {Prj, Length[prices]}]]

IsNESym determines whether a set of capacities and prices is a Nash equilibrium of a 2 player symmetric game. It simply checks whether a figure is the maximum of a row and of the "corresponding" column.
IsNESym[Poscapi_, Pospricei_, Poscapj_, Pospricej_] :=
And[PayOffs[[Poscapi]][[Poscapj,
Pospricei]] [[Pospricej]] ==
Max[colis[Poscapj, Pospricej]],
PayOffs[[Poscapj]][[Poscapi,
Pospricej]] [[Pospricei]] ==
Max[rowis[Poscapj, Pospricej]]]

The PayOff Matrix with its current values

TableForm[PayOffs]

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<tr>
<th></th>
<th>0.</th>
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</tr>
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<tbody>
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<td>0.</td>
<td>-1</td>
</tr>
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<td>1.5</td>
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</tr>
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<td>-3.5</td>
</tr>
<tr>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

A check of the payoff matrix for the existence of Nash equilibria

TableForm[Table[IsNESym[ki, Pri, kj, Prj],
{ki, Length[capacities]},
{kj, Length[capacities]}, {Pri, Length[prices]},
{Prj, Length[prices]}]]

<p>| | | |</p>
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Bibliography


Binmore, K. G.: 1992, Fun and Games, Heath, Lexington, MA.


Borenstein, S., Bushnell, J. and Stoft, S.: 1997, the competitive effects of transmission capacity in a deregulated electricity industry, University of California Energy Institute POWER series.


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