Auctions: Theory and Practice

Inaugural (2003) *Toulouse Lectures*

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Abstract

This book is a non-technical introduction to auction theory; its practical application in auction design (including many examples); and its uses in other parts of economics. It can be used for a graduate course on auction theory, or – by picking selectively – an advanced undergraduate or MBA course on auctions and auction design.

Part A introduces the basic theory. Part B shows how modern auction-theoretic tools illuminate a range of mainstream economic questions that are superficially unconnected with auctions. Part C discusses practical auction design. Part D describes the one-hundred-billion dollar 3G mobile-phone license auctions. None of the writing is technical, except in the Appendices.

The material was presented as the inaugural (2003) *Toulouse Lectures in Economics* and is forthcoming at *Princeton University Press*.

This document contains the Contents, Preface and Introduction to the book. A draft of the FULL BOOK is available at http://www.paulklemperer.org.[1]

Keywords**:** Auctions, Bidding, Auction Theory, Mechanism Design, Telecommunications, Spectrum Auctions, 3G, UMTS

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[1]The book can be ordered from: (for UK/Europe) UCCP, John Wiley & Sons Ltd., 1 Oldlands Way, Bognor Regis, PO22 9SA, UK. Tel: +44 1243 843294 Fax: +44 1243 843296;
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Preface

February 2000 was a stressful month for me: the UK 3G auction was about to begin. For over two years I had been working with the UK government to design the world's first auction of spectrum for "third generation" (3G) mobile-phone services. A lot was at stake. If our auction worked well, it would allocate the spectrum efficiently and raise a lot of money, but many previous auctions had been embarrassing flops that had failed to generate the sums expected. This time the politicians were hoping for billions of dollars.

We had written numerous papers, developed theories, and tested prototype auction designs in experiments. But would it all work on the day? What might go wrong? The bidders all had armies of consultants and lawyers. What loopholes in the rules might they find to exploit? Could they find a devious way to coordinate their bidding and so avoid competing against each other? Or might our rules actually have discouraged some potential bidders from entering the auction at all – so destroying competition for a different reason?

The 1990s had been littered with examples of auctions – especially of new products or services – that had gone disastrously wrong. Several U.S. auctions had fallen down because bidders signalled to each other by including lot identification numbers and even phone numbers as the final digits of their bids. The winner of a New Zealand auction had bid $7 million dollars, but the rules required it to pay only $5,000. Only three bidders had turned up for a German auction of three blocks of spectrum, which therefore sold only at the tiny reserve price. Closer to home, an auction of U.K. television broadcasting rights sold licences for some regions of the country at prices less than one ten-thousandth of others. U.K. electricity auctions were widely criticized for yielding collusive prices. So would our new auction end up as just another humiliating giveaway?

The tension only mounted over the seven weeks the auction ran. The auction started well. Day after day the prices climbed, but we continued to worry about what we might

have missed, and what could still go wrong. As the prices kept rising through 150 rounds of bidding, and records started falling, nerves gave way to astonishment. Still, it was an enormous relief when the gavel finally came down on five bids totalling over 34 billion dollars – our auction had raised more money than any previous auction in history. It was even more of a relief when the bidders all paid at the appointed time, and the sale process was finally over, without a hitch.

In the following months, other countries held 3G auctions. The results were very different. Whereas our auction raised almost 600 dollars per head of population, most countries earned far less revenue, and the Swiss made only 20 dollars per head. The key reason was, quite simply, how the auctions were designed: good auction design matters enormously.

This book is in large part a story of the thinking behind the UK's auction. I survey the basic theory of how auctions work; emphasise the practical lessons that can make the difference between successful auctions and catastrophic ones; and discuss the one hundred billion dollar 3G mobile-phone auctions as a case study.

I also explore the connections with other areas of economics that originally drew me into studying auctions. The increasing use of auction theory to develop insights into *other* parts of economics has been one of the most exciting parts of my professional life. So I look in detail at the relationships between auctions and other economic questions. I show how modern auction theory can illuminate such diverse phenomena as booms and busts in housing markets, financial crashes and trading 'frenzies', political lobbying and negotiations, the differing costs of alternative legal systems, and the relative intensities of different forms of industrial competition. Thus the tools of auction theory help to explain many issues in economics - and every economist should learn about auctions.

Overview

This book can be used by a general reader, for a graduate course on auction theory, or – by picking more selectively – an advanced undergraduate or MBA course on auctions and auction design.

None of the writing is technical, except in the Appendices. (Indeed there are barely any mathematical symbols, let alone equations, outside footnotes and Appendices).

Part A introduces the basic theory, and surveys the existing literature. It includes exercises, and technical Appendices.

Part B shows that modern auction-theoretic tools and intuitions can provide extremely useful arguments and insights in a broad range of economic settings. Auction theory has turned out to be surprisingly powerful in places that are superficially unconnected with auctions – many economic contexts that do not at first sight look like auctions can be recast to use auction-theoretic techniques.

Part C argues that important insights also flow in the other direction – from other parts of economics to the analysis of auctions: in particular, the key issues in practical auction design are not so much those that have been addressed by recent advanced auction theory, but rather the traditional industrial-organization issues of collusion, entry-deterrence, etc. I give numerous examples. I then discuss economic policy-making more broadly, including the need to pay attention to political pressures and to the wider economic context, but illustrate these points using auction examples.

Part D describes and evaluates the world-record-setting 2000-01 3G mobile-phone license auctions, as a case study for the earlier Parts. I discuss the design *process*, as well as the designs and the overall successes of the different auctions. I also analyse why bidder strategies were a little different from those that would be suggested by the

elementary theory described in Part A. I conclude by considering the merits of running auctions versus the alternatives.

Using this Book

The independent **general reader** may read the Parts in whichever order interests him or her – each Part is self-sufficient and can be read in isolation, even by those without any previous background in auction theory.

A **graduate course** on auctions (or a segment of a core microeconomics course) would dwell on Parts A and B, and cover Parts C and D more cursorily. It should include the Exercises and the technical appendices to chapter 1, and could usefully be complemented by some additional readings from those discussed in chapter 1. (These further readings are reprinted in Klemperer, 2000.)

Undergraduate lectures might cover the first half of Part A (and, perhaps, some of chapter 1's appendices), and Parts C and D.

An **MBA course** segment might focus on Parts C and D (except chapter 7).

Some suggested course outlines are at the end of the volume.

Acknowledgements

Most of this material was first published in 2002–2003. The exception is chapter 1 which was first published in 1999; I have therefore added a short Afterword to that chapter to bring it up-to-date.

Since the papers were originally written as stand-alone contributions, there is inevitably a little repetition, but the overlaps should be obvious and cause the reader no problems.

The papers were originally published as follows:

Chapter 1 (except Afterword and Exercises). Auction Theory: A Guide to the Literature. *Journal of Economic Surveys* 1999, 13(3), 227-86.[2]

Chapter 2. Why Every Economist should Learn some Auction Theory. *Advances in Economics and Econometrics: Theory and Applications* (Dewatripont, Hansen and Turnovsky eds.) 2003, 1, 25-55 (reprinted by permission of Cambridge University Press).[3]

Chapter 3. What Really Matters in Auction Design. *Journal of Economic Perspectives* 2002, 16(1), 169-189 (reprinted by permission of the American Economic Association).

Chapter 4. Using and Abusing Economic Theory. *Journal of the European Economic Association* 2003, 1(2-3), 272-300 (reprinted by permission of the European Economic Association).[4]

Chapter 5. How (Not) to Run Auctions. *European Economic Review* 2002, 46(4-5), 829-845 (reprinted by permission of Elsevier).[5]

Chapter 6. The Biggest Auction Ever. *Economic Journal* 2002, 112, C74-C96, with Ken Binmore (reprinted by permission of Blackwell Publishing, and the Royal Economic Society).

Chapter 7. Some Observations on the British 3G Telecom Auction. *Ifo Studien* 2002, 48(1), 115-120, and Some Observations on the German 3G Telecom Auction. *Ifo Studien* 2002, 48(1), 145-156 (reprinted by permission of the Ifo Institute).[6]

Chapter 8. The Wrong Culprit for Telecom Trouble. *Financial Times* November 26 2002, 21.

Exercises. Oxford University MPhil in Economics Examination. Reprinted by permission of Oxford University.

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[2] Also reprinted in *The Current State of Economic Science*, S. Dahiya (ed.), 1999.
[3] Also *Invited Lecture* to Eighth World Congress of the Econometric Society 2000.
[4] Also *Alfred Marshall Lecture* to European Economic Association 2002, and also reprinted in *Advances in Economics and Econometrics: Theory and Applications*, S. Hurn (ed.), forthcoming.
[5] Also reprinted in *Spectrum Auctions and Competition in Telecommunications*, G. Illing (ed.), MIT Press, forthcoming.
[6] Both papers also reprinted in *Spectrum Auctions and Competition in Telecommunications*, G. Illing (ed.), MIT Press, forthcoming.

Collecting these papers together in a volume was inspired by the invitation to give the inaugural series of the Toulouse Lectures which were based on them. I am most grateful to Jacques Cremer, Jean-Jacques Laffont, and Jean Tirole for the invitation and for their hospitality during my visit, and to Richard Baggaley of the Princeton University Press for his smooth running of the whole publication process.

I could not have written any of these papers without the benefit of the enormous amount I have learnt from my friends and colleagues. Many of these are thanked in the acknowledgements to the individual chapters, but Jeremy Bulow and Marco Pagnozzi deserve special thanks.

Finally, I was the principal auction theorist advising the UK Government on the design of its "3G" mobile-phone auction,[7] I am a Member of the UK Competition Commission, and I have advised several other Government agencies in the UK, US, and EU, but the views expressed in this book are mine alone. Furthermore, although some observers thought some of the behavior described below warranted regulatory investigation, I do not intend to suggest that any of it violates any applicable rules or laws.

[7] Ken Binmore led the team and supervised experiments testing the proposed designs.

Introduction

Auction theory is one of economics' success stories. It is of both practical and theoretical importance: practical importance, because many of the world's most important markets are auction markets, and good auction theory has made the difference between successful auctions and disastrous ones; theoretical importance, because lessons from auction theory have led to important insights elsewhere in economics.

Auctions are not a new idea: the Babylonians auctioned wives, the ancient Greeks auctioned mine concessions and, in addition to their notorious slave auctions, the Romans auctioned everything from war booty to debtors' property. In the modern world, auctions are used to conduct a huge volume of economic transactions. Governments use them to sell treasury bills, foreign exchange, mineral rights including oil fields, and other assets such as firms to be privatized. Government contracts are typically awarded by procurement auctions, which are also often used by firms subcontracting work or buying services and raw materials. In these cases, of course, the auctioneer is seeking a low price rather than a high price. Houses, cars, agricultural produce and livestock, art and antiques are commonly sold by auction. Other economic transactions, for example takeover battles, are auctions by another name.

The range of items sold by auction has been greatly increased by e-commerce, and in the last decade or so there has also been an explosion of interest in using auctions to set up new markets, for example, for energy, transport, and emissions permits. Although many of these markets do not look like auctions to the layperson, they are best understood through auction theory. (For example, electricity markets are best described and analyzed as auctions of infinitely-divisible quantities of identical goods.) The auctions of mobile phone licenses across the world are only the most famous of the new auction markets.

Not only are auctions an increasingly important part of the way the economy allocates resources, but also economists have increasingly realised the wider importance of auction theory: it has been the basis of much fundamental theoretical work not directly related to auctions. Many economic contexts that do not at first sight look like auctions can be recast to use auction-theoretic techniques, and a good understanding of auction theory is valuable in developing intuitions and insights that can inform the analysis of many mainstream economic questions.

This book considers the theory of auctions, practical auction design including case studies, and the application of auction theory to *other* areas of economics.

A. Auction theory

Two basic designs of auction are most commonly used: the ascending auction, in which the price is raised successively until only one bidder remains and that bidder wins the object at the final price she bid; and the first-price sealed-bid auction, in which each bidder independently submits a single bid without seeing others' bids, the object is sold to the bidder who makes the highest bid, and the winner pays the amount she offered.

The key result in auction theory is the remarkable *Revenue Equivalence Theorem* which, subject to some reasonable-sounding conditions, tells us that the seller can expect equal profits on average from all the standard (and many non-standard) types of auctions, and that buyers are also indifferent among them all. William Vickrey's Nobel Prize was in large part awarded for his (1961, 1962) papers which developed some special cases of the theorem, and Riley and Samuelson (1981) and Myerson (1981) offer more general treatments.

Much of auction theory can be understood in terms of this theorem, and how its results are affected by relaxing its assumptions of a fixed number of "symmetric", risk-neutral

bidders, who each want a single unit, have independent information, and bid independently. Myerson's (1981) paper shows how to derive optimal auctions (that is, auctions that maximize the seller's expected revenue) when the assumption of symmetry fails. Maskin and Riley (1984) consider the case of risk-averse bidders, in which case the first-price sealed-bid auction is the most profitable of the standard auctions. Milgrom and Weber (1982) analyzed auctions when the assumption of independent information is replaced by one of "affiliated" information, and showed that the most profitable standard auction is then the ascending auction. (Roughly, bidders' information is affiliated if when one bidder has more optimistic information about the value of the prize, it is more likely that other bidders' information will also be optimistic.) Models of auctions in which bidders bid for multiple units lead to less clear conclusions. For practical auction design, however, it is probably most important to remove the assumptions that the number of bidders is unaffected by the auction design, and that the bidders necessarily bid independently of each other; sealed-bid designs frequently (but not always) both attract a larger number of serious bidders and are better at discouraging collusion than are ascending designs (Klemperer 1998, 2002).

Part A covers all these issues and a range of other topics including double-auctions, royalties, incentive contracts, budget constraints, externalities between bidders, and the winner's curse. Appendices contain technical details, some simple worked examples, exercises (with solutions) at first- and second-year graduate student level, and bibliographies.

*B. Applications to **other** areas of economics*

There are close connections between auction theory and other areas of economics.

By carefully analyzing very simple trading models, auction theory is developing the fundamental building-blocks for our understanding of more complex environments. It has been important in developing our understanding of other methods of price formation,

including posted prices and negotiations in which both the buyer and seller are actively involved in determining the price.

There are especially close connections between the theories of auctions and perfect competition. Wilson (1977), Milgrom (1979), and others have developed conditions under which the sale price of an object whose value is actually the same to all bidders converges to this value as the number of bidders increases, even though each individual bidder has only partial information about this value. The fact that an auction can thus fully aggregate all of the economy's information helps to support some of our ideas about perfect competition and rational expectations equilibrium.

There is also a close analogy between the theory of optimal auctions and that of monopoly pricing; the analysis of optimal auctions is "essentially equivalent to the analysis of standard monopoly third-degree price discrimination" (Bulow and Roberts, 1989). Thus insights can be translated from monopoly theory to auction theory and vice-versa.

Because auctions are such simple and well-defined economic institutions, they have become an important testing ground for economic theory, and especially game theory. So auctions are also the basis of flourishing new empirical and experimental literatures.

More recently, auction-theoretic tools have been used to provide useful arguments in a broader range of contexts – including many that do not, at first sight, look like auctions – starting with models of oligopolistic pricing, running through non-price means of allocation such as queues, wars of attrition, lobbying contests, other kinds of tournaments, and rationing, and extending to models in finance, law and economics, labor economics, political economy, etc.

Part B discusses the connections between auctions and other areas of economics, emphasizing these broader uses of auction theory. It aims to demonstrate that auction theory should be a part of every economist's armory.

C. Practical auction design

Although there are now many extremely successful auction markets – and economists have much to be proud of in their role in developing them – there have also been some notable fiascos. Certain auctions of TV franchises, companies, electricity, mobile-phone licenses, etc., have failed badly – even comically – providing useful illustrations of what really matters in practical auction design.

The most important point is that everything depends on the context. Auction design is *not* "one size fits all". A good auction needs to be tailored to the specific details of the situation, and must also reflect the wider economic circumstances.

Second, as stressed above, the critical issues are usually the bread-and-butter industrial-organization problems of encouraging entry and discouraging collusion. The more subtle points addressed by recent advanced auction theory are, more often than not, of lesser importance. So, for example, the Anglo-Dutch auction – a hybrid of the sealed-bid and ascending auctions – may often perform better than standard ascending auctions which are particularly vulnerable to collusive, predatory, and entry-deterring behaviour.

Finally, when advising governments, auction designers (and economic policy-makers more generally) need to be sensitive to the dangers posed by political and administrative pressures, and make their proposals robust to changes that are likely to be imposed.
Part C discusses all these issues, using numerous examples. Chapter 3 focuses on practical auction design, while chapter 4 takes a broader perspective on the policy-making process, but illustrates its points using examples of auctions.

D. Case study

The 2000-01 '3G' mobile-phone license auctions not only raised one hundred billion dollars and attracted intense media scrutiny; they also provide an excellent illustration of our points about practical design. Even though the licences sold were very similar in each of the nine west European auctions, the different auction designs resulted in revenues that varied from less than 20 Euros per capita in Switzerland to over 650 Euros per capita in the UK.

Part D describes and evaluates the 3G auctions as a case study for the earlier Parts. I describe the design, and overall success, of each of the auctions (chapter 5); discuss the design *process*, and give fuller details of the successful UK auction which I helped design (chapter 6); and analyze why bidder strategies were a little different from those suggested by elementary theory (chapter 7). Finally, I discuss the merits of running auctions versus the alternatives (chapter 8): although it is now fashionable to blame the 3G auctions for all the telecommunication industry's problems, there is absolutely no foundation for this. In spite of the design errors that were made, allocating the 3G licences by auctions was clearly the correct policy.

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