

# **Rationalizing the UMTS Spectrum Bids: The Case of the UK Auction**

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# Rationalizing the UMTS Spectrum Bids: The Case of the UK Auction\*

By *Tilman Börgers* and *Christian Dustmann*

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## I. Introduction

During the years 2000 and 2001 most European countries have awarded licenses to mobile telephone companies which allow these companies to use radio spectrum for the operation of third generation mobile telephone services (UMTS licenses). The methods adopted for the award of these licenses have differed widely across European countries. Some countries such as Finland and Spain have bureaucratically decided how many licenses there should be, of which size in terms of available radio spectrum these licenses should be, and which companies should own them. Other countries such as Germany and Austria have used auction type procedures to determine the number and size of licenses as well as the license holders. Finally, some countries such as the

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\* A companion paper (*Börgers and Dustmann (2001)*) gives a more comprehensive overview of the UMTS auction in the United Kingdom. A revised version of *Börgers and Dustmann (2001)* will also report additional insights into bidders' behaviour which we found after completing the current paper. The authors are grateful to *Paul Klempner*, *Pedro Rey*, and *Klaus Schmidt* for comments. This paper was written while *Tilman Börgers* was visiting the Center for Economic Studies in Munich and *Christian Dustmann* was visiting the Center for Labor Economics in Berkeley. Both authors thank their respective host institutions for generous hospitality. *Tilman Börgers'* research was also supported by the Economic and Social Research Council (ESRC) through the Center for Economic Learning and Social Evolution (ELSE). *Tilman Börgers* was a member of a group of economists who advised the United Kingdom's Radiocommunications Agency on the design of the auction which is discussed in this paper. This paper is based on publicly available information only. No use is made of confidential information which was acquired while advising the Radiocommunications Agency. All opinions expressed in this paper are those of the authors alone.

United Kingdom and the Netherlands have chosen an intermediate procedure where the number and size of licenses was determined by bureaucratic methods, but the allocation of these licenses to firms was determined in an auction.

The outcomes of the licensing process have also differed widely across European countries. Finland and Spain, for example, have issued four UMTS licenses, the United Kingdom and the Netherlands have issued five UMTS licenses, and Germany and Austria have issued six such licenses. In Finland licenses were essentially given away for free. In Spain the total payments to the government by license holders per head of the population were only € 12. In Austria all successful bidders together paid approximately € 103 per head of the population. In the Netherlands license holders paid approximately 169 Euros per head of the population to the government. But in Germany winning bidders paid € 619 and in the United Kingdom they paid € 642 per head of the population.<sup>1</sup>

The large payments in the United Kingdom and Germany have attracted much attention. The question arises whether the bids which companies made in the auctions conducted by these two countries were based on careful business plans, or whether they were the result of some form of "bidding fever". A policy reason for being interested in this question is that the purpose of these auctions, as stated by the United Kingdom government and German law, was to allocate spectrum efficiently.<sup>2</sup> How exactly efficiency is to be understood in this context is not obvious, but a necessary condition for efficiency is presumably that bidders rationally consider the value of licenses, and that these valuations are expressed consistently in their bids. If this was not the case in the UK or in Germany, then one can reasonably entertain doubts whether an efficient allocation was achieved.

The purpose of this paper is to assess whether the auction bids for UMTS licenses can be interpreted as rational bids which are based on careful valuations of the licenses. We shall focus on the United Kingdom's UMTS auction.<sup>3</sup> The United Kingdom's UMTS auction was a simultaneous ascending auction.<sup>4</sup> Five non-identical licenses were for sale. The auction was organised in rounds. In each round the currently leading bidder for each license could not change its bid. All bidders who were not currently leading on some license had to either

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<sup>1</sup> The information about the number of licenses and the payments made was obtained from the following websites: [www.itu.int](http://www.itu.int) (Finland and Spain), [www.tkc.at](http://www.tkc.at) (Austria), [www.regtp.de](http://www.regtp.de) (Germany), [www.spectrumbauctions.gov.uk](http://www.spectrumbauctions.gov.uk) (UK), and [www.wapworld.nl](http://www.wapworld.nl) (Netherlands). Currency rates were obtained from [www.oanda.com](http://www.oanda.com), and population statistics from [www.oecd.org](http://www.oecd.org).

<sup>2</sup> In the UK, Telecommunications Minister *Barbara Roche* emphasized efficiency as the main goal of the auction in a statement to the House of Commons on 18 May 1998. In Germany, § 44 of the *Telekommunikationsgesetz*, i.e. the law which governs spectrum allocation, states that efficiency and absence of technical interference are the main goals of spectrum allocation.

<sup>3</sup> An analysis of Germany's auction is for two reasons harder: firstly, the auction rules in Germany were more complicated than in the UK, and secondly, unlike the UK, Germany did not publish all of the bids made in the auction, but only some.

<sup>4</sup> The following account of the rules of the UK auction is very brief, and leaves out many important details. A more complete account of the rules of the auction is in Section II below.

overbid the currently leading bid for one license, or they had to withdraw from the auction. To overbid a leading bid one had to raise that bid by a minimum percentage. Withdrawal was irreversible. The auction closed once bidding on all licenses had stopped. The currently leading bidders were then awarded the licenses, and had to pay their last bids.

All bids in the United Kingdom's auction, including bids which were not the highest bids, were instantaneously published on the internet.<sup>5</sup> These data form the basis for our paper. We take as our starting point a naive theory of what it would mean to bid on the basis of rational valuations of the licenses. This is the theory of *private values* and *straightforward bidding*. According to this theory bidders enter the auction with fixed valuations for each license, and do not revise these valuations during the auction. This is the "private values" part of the theory. The "straightforward bidding" part says that firms bid in each round for the license for which the difference between the value of the license and the minimum bid that is admissible for that license is largest, provided that this difference is positive. Moreover, bidders only place minimal admissible bids. Once the minimum bid for all licenses is larger than their value the firm withdraws.<sup>6</sup>

We take this naive theory as a benchmark, not as a plausible conjecture. Indeed, we find that the data refute this naive theory of bidding for the UK auction very clearly. The most important deviation from the theory concerns the bidders' revealed value *differences*. Under the theory of private values and straightforward bidding the bids placed in the auction contain important information about these differences. To explain this we give a simple example. Suppose that only two licenses are for sale, *A* and *B*, and that in a certain round the smallest admissible bid for *A* is £ 10 more than the smallest admissible bid for *B*. Consider a bidder who chooses to bid for *A*. Then this bid reveals that this bidder's value of *A* is at least £ 10 larger than his value for *B*. Now every bidder typically has to bid many times throughout the auction, and each new bid reveals further information about the valuation differences. For example, if the same bidder bids later for *B* when the price difference is £ 12 then we have not only a lower (£ 10) but also an upper bound (£ 12) for the difference of the values of *A* and *B*. But now suppose that the same bidder bids in an even later round for *B* when the price difference is only £ 8. Then we have an inconsistency. This bidder's behaviour does not seem to reveal a consistent view of what the value difference is.

The evidence against straightforward bidding with private values which we provide below shows that bidding in the UK's spectrum auction was affected by inconsistencies of exactly the type which we have just described. The inconsistencies concerned the revealed difference between the value of a "large" (in terms of spectrum) license and the value of a "small" license. Several important

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<sup>5</sup> At the time at which this paper was written this information was publicly available on the internet at: [http://www.spectrumbauctions.gov.uk/auction/auction\\_index.htm](http://www.spectrumbauctions.gov.uk/auction/auction_index.htm).

<sup>6</sup> This theory of bidding in simultaneous ascending auctions is studied in one of the fundamental theoretical papers on simultaneous ascending auctions (*Milgrom* 2000). If bidders hold private values then straightforward bidding is rational (see appendix 1 of *Börger* and *Dustmann* 2001) and it implies efficiency of the outcome of the auction (see appendix 2 of *Börger* and *Dustmann* 2001).

bidders' behaviour does not reveal any consistent estimate of this value difference. In fact, for most of these bidders their estimate of the difference seems to have increased dramatically during the auction, in one case even by a factor of six.

Note that this finding does *not* necessarily imply that the companies which bid in the UK auction did not have careful valuations of the UMTS licenses, or that their bidding strategies were irrational. Straightforward bidding with private values is a very narrow interpretation of the general intuitive idea of "rational bidding that is based on a careful valuation of the licenses". Wider interpretations might allow, for example, for valuations which change during the auction. One possible rationale for this would be that a "common value" element was present in the auction. As a consequence companies may have learned from observing other companies' bidding behaviour during the auction about the license values. The learning might have led to a change in their valuations which to a naive observer looks like an inconsistency. Another possibility is that allocative externalities may have been present. Such externalities exist if companies' valuations of licenses depend on which other companies win a license. Companies' beliefs about the likely winners of other licenses might have changed during the auction, and this may have led to apparent inconsistencies.

The contribution of the current paper is to provide a more detailed assessment of the hypothesis that behaviour in the UK auction was consistent with "rational bidding that is based on a careful valuation of licenses" provided that a sufficiently wide interpretation of this intuitive idea is adopted. Because companies' behaviour in the UK auction differed a lot, we focus on case studies of individual companies. We select three companies which played a particularly important role in the auction, and for which we found in our earlier paper inconsistencies in their evaluation of the difference between licenses. These three companies are: BT3G, TIW and NTL Mobile. BT3G and TIW both won a license in the UK auction. NTL Mobile was the last company to drop out of the UK auction.

The three companies which we have selected for this paper were, together with Vodafone, the most persistent bidders for the two large licenses which the UK government put up for sale. As Vodafone's behaviour is very easily understood<sup>7</sup> one can thus also say that our paper provides a detailed analysis of the bidding races for the two large licenses. We begin by providing detailed round by round descriptions of these companies' bidding behaviour. In this context we also show that these companies' bidding is inconsistent with the theory of straightforward bidding with private values. We then discuss the extent to which alternative hypotheses can explain the available evidence. Our main finding is that there is no hypothesis for which we can provide strong evidence from our data. However, there are some hypotheses which seem plausible, and which, if true, would not necessarily leave a lot of "footprints" in our data.

An example of a hypothesis for which we might hope to find strong evidence in our data is the hypothesis that allocative externalities were present. Suppose that we maintain the myopia hypothesis implicit in the theory of straightforward bidding, and postulate that companies bid in each round for that license which

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<sup>7</sup> See our comments in Section IV.

currently offers the best value, assuming that the leaders on all other licenses will not change. Then we should find that companies reveal consistent valuation differences once we condition on the current leaders on other licenses. In this paper we give evidence that this was not the case in the UK auction.

An example of a hypothesis which does not leave a lot of footprints in our data is that companies learned from other companies' bids about the true value of licenses. Which precise form such learning takes depends on a companies' prior beliefs about the value of licenses, about the information available to other bidders, and about the strategies adopted by other bidders. Depending on how these beliefs are specified, relatively arbitrary belief paths can be obtained, and consequently it is difficult to tell from observed bidding behaviour whether this form of learning played a role or not. We shall have to rely on plausibility considerations. In some cases, these considerations lead us to conclude that social learning of the type described here may well have played a role.

We cannot reach an unambiguous answer regarding the question whether the UK bids can be explained as rational bids based on careful valuations of the UMTS licenses for sale. However, the UK experience provides some reason for caution. Bidders' behaviour in the UK auction remains ill understood. It is unclear whether this auction achieved its efficiency objective. For policy questions an important further question is, of course, whether better alternative allocation methods exist. Our paper has nothing to say about this question.

We conclude this introduction with a brief discussion of related literature. This paper has a companion paper (Börgers and Dustmann 2001) in which, instead of conducting case studies for particular companies, we provide a more comprehensive overview of the UK auction.

Our argument that the UK bidding data raise important open questions runs counter to the interpretation of these data by other authors. Plott and Salmon (2001) have used the UK data to estimate different companies' license valuations, and have then determined the percentage of bids which are in accordance with these estimates and straightforward bidding. The percentages which they find vary substantially from company to company, but overall they conclude that the theory of private values and straightforward bidding does well. We come to a more negative conclusion than they do because we regard the percentages of unexplained bids as more important than Plott and Salmon do. Indeed, an easy calculation shows that if the private values which Plott and Salmon estimate were correct, then some of the bids which their approach leaves unexplained would have caused losses between one and two billion Pounds, had they been successful.

Plott and Salmon also investigate the extent to which estimates based on the first 75 or 100 rounds allow an outside observer to predict the final licence winner and the price which they will pay. They find that these predictions are reasonably accurate. Our investigations show that any efforts to predict on the basis of the first 75 or 100 rounds not just the final winners, but also the bids placed in the intervening rounds (101 to 150) would lead to very inaccurate forecasts for some companies.

The UK auction data have also been examined by Peter Cramton in his report for the National Audit Office (Cramton 2001). Cramton writes that “Most of the bidders pursued a strategy of bidding on the license that represented the best value. Bidders thus switched from license to license as the prices changed. ... The pricing dynamics were predictable, although certainly not the absolute values of prices” (Cramton 2001, p.50). Cramton’s report does not include a detailed discussion of empirical evidence. We argue that if one adopts the interpretations of the phrase bidding for best value described in this paper, then the evidence that bidders bid for best value is not very strong. Additional discoveries about the behaviour of BT3G, made after completing the current paper, will be reported in a revised version of our companion paper.

The remainder of this paper is organized as follows. In section II we describe the background to the United Kingdom’s auction and provide some summary information about the outcome of the auction. To illustrate our benchmark of private values and straightforward bidding we discuss in section III the bids made by Orange. These bids were largely in line with our benchmark hypotheses. Section IV then considers in more detail the behaviour of BT3G. Section V conducts a similar case study for TIW and NTL Mobile. Section VI concludes.

## II. Background<sup>8</sup>

The sale of UMTS licences in the United Kingdom was conducted by the “Radiocommunications Agency”. This is an agency of the UK’s government. The Radiocommunications Agency sold five licences, labelled A, B, C, D and E. Each licence entitles its owner to the use of a part of the spectrum that is identified in the licence. Licence A consists of 15 + 15 MHz of paired spectrum and 5 MHz of unpaired spectrum.<sup>9</sup> Licence B consists of 15 + 15 MHz of paired spectrum. Licences C, D and E consist of 10 + 10 MHz of paired spectrum and 5 MHz of unpaired spectrum. The licences remain in force until 2021. At the time of the auction licences could not be traded, but the government indicated that it might enable licence trading during the duration of the licences. The licences came with an obligation to roll out a network covering at least 80% of the UK population by 2007. Licence A was reserved for a new entrant into the UK’s mobile phone market. The incumbent four mobile telephone operators were not allowed to bid for license A. The four incumbent mobile telephone operators in the United Kingdom were at the time of the auction: Vodafone, Cellnet (owned by British Telecom), Orange, and One2One. Their mobile telephone subscriber shares in the UK were on 1 May 1999: Vodafone (37.3%), Cellnet (30.1%), Orange (17.2%) and One2One (15.4%).

The auction was organized in “rounds”. In each round, except the first round, each licence had a “current price” and a “current price bidder”. In each round the

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<sup>8</sup> This section reviews some material that we originally presented in *Börgers and Dustmann* (2001). For a detailed account of the discussions which preceded the UK auction and of the role of academic economists in these discussions see *Binmore and Klempner* (2002).

<sup>9</sup> Paired spectrum allows more efficient use of the spectrum than unpaired spectrum.

current price bidders had to remain inactive. All other bidders had three actions available to them. (1) They could make a bid for one of the licences. This bid had to exceed the “current price” by a minimum increment that was announced by the Radiocommunications Agency before the round began. (2) They could ask for a “waiver”, i.e. do nothing. Each bidder could ask for a total of three waivers only in the auction. (3) They could withdraw from the auction. Withdrawal was final: a bidder who withdrew could not re-enter the auction.

The highest bid for each licence became the “current price” in the next round, and the bidder who placed that bid became the “current price bidder” in the next round. If no bid was placed on a licence then the “current price” and the “current price bidder” remained unchanged. If several bidders placed identical highest bids on a licence then the “current price bidder” was randomly selected from these bidders. The auction ended when the last bidder who was not “current price bidder” for some licence had withdrawn. Each “current price bidder” was then awarded its licence at the “current price”.

The minimum bids for the five licences in the first round were: A (£ 125 million) B (£ 107.1 million), C, D and E (£ 89.3 million). In the first round all bidders had to be active and had to choose one of the three actions described above. In later rounds the minimum increment was  $x\%$  of the current price, where  $x$  was initially 5, and was later chosen by the Radiocommunications Agency.

Interested bidders had to pay an initial deposit of £ 50 million. A bidder who wished to increase his bid to £ 400 million had to pay an additional deposit of £ 50 million. Winning bidders could choose between either paying immediately or deferring part of the payment, where then an interest rate would be applied.

All four incumbents entered the auction. Cellnet participated in the auction as BT3G. In addition, nine outsiders joined the auction: NTL Mobile, 3G UK, Worldcom, TIW, Telefonica, Spectrumco, Crescent, One.Tel, and Epsilon. The government agreed to regard these companies as independent bidders. Orange was owned by Mannesmann who, in turn, had just been taken over by Vodafone, but Vodafone gave an undertaking to the government to dispose of Orange after the auction, and to take measures which ensured the independence of Orange's bidding in the auction.

The auction opened on 6 March 2000 and closed on 27 April 2000. The number of rounds was 150. The typical number of rounds per day was five. The minimum increments by which a bidder had to overbid the previously highest bid was initially 5% but was lowered in several steps to 1.5%.

The first company withdrew in round 94. All withdrawal decisions are listed in table 2. The final winners of the auction, and the winning bids, are listed in table 1.

All companies which won licences opted to pay for these licences immediately although the government had offered an option of deferred payment. By September 2000 all licences had been issued.

Table 1

**Winners**

Licence	Company	Winning bid
A	TIW	£ 4,384.7 million
B	Vodafone	£ 5,964.0 million
C	BT3G	£ 4,030.1 million
D	One2One	£ 4,003.6 million
E	Orange	£ 4,095.0 million

Table 2

**Withdrawals**

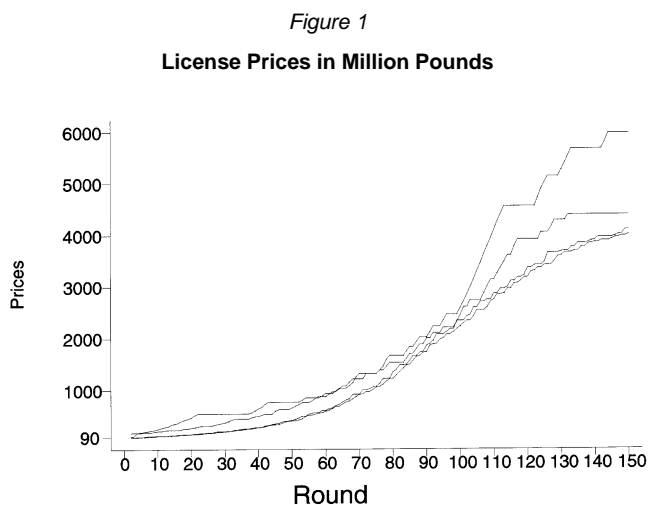
Company	Withdrew in round
NTL Mobile	150
Telefonica	133
Worldcom	121
One.Tel	101
Epsilon	98
Spectrumco	97
3G UK	95
Crescent	94

Table 2 shows that the first five bidders to withdraw from the auction withdrew in quick succession. The withdrawals began in round 94 and ended in round 101. It therefore seems natural to call rounds 1 to 101 “phase 1” of the auction. After Telefonica withdrew from the auction in round 133 it was clear that the auction would end once one further bidder withdrew. Therefore, these rounds constituted the “hot phase” of the auction, and we shall call them “phase 3”. We shall call the intermediate rounds, i.e. rounds 102 to 133, “phase 2” of the auction. In phase 2 the number of bidders was thus first eight and then seven. It appears natural to divide phase 2 further into phases 2a and 2b, where phase 2a consists of rounds 102 to 121 in which the number of bidders was eight, and phase 2b, rounds 122 to 133, when the number of bidders was seven. For simplicity we shall mostly treat phase 2 as just one phase. However, where this provides additional information, we shall also employ the distinction between phases 2a and 2b.<sup>10</sup>

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<sup>10</sup> We are grateful to *Paul Klempere*r for suggesting the distinction between phases 2a and 2b.

Next we indicate how the prices of the licenses developed during these three phases. Here, and in the following, we mean by the “price” of a licence in any particular round the minimum bid that is needed to overbid the currently leading bidder in that round. Thus the price of a licence in a round equals the bid made by the currently leading bidder plus the minimum increment.<sup>11</sup> In figure 1 we show the prices of licenses A and B as well as the price of the most expensive and the price of the cheapest of licenses C, D and E in every round. The figures show that the speed at which the prices of licenses A and B rose during the auction accelerated in phase 2, and slowed down significantly in phase 3.



Top Line: license B; next line: license A; next line: maximum of the prices of C, D and E; bottom line: minimum of the prices of C, D and E.

### III. Straightforward Bidding with Private Values: The Case of Orange

Our focus in this paper is on documenting and explaining deviations from straightforward bidding and private values. To begin with, however, we give the example of a company whose behaviour is largely in line with these hypotheses. We do this, firstly, to clarify how the data can confirm these hypotheses, and, secondly, to indicate that not *all*, but only *some* firms' bidding behaviour deviates from the hypotheses.

<sup>11</sup> Notice that our use of the expression “price” of a license differs somewhat from the Radiocommunication Agency's use of the expression “current price” which was explained earlier in this section.

The bidder whose behaviour we consider in this section is Orange, one of the four incumbents in the mobile telephone market in the UK. Orange won license E. Although Orange's behaviour was roughly as predicted by private values and straightforward bidding, it did not satisfy these hypotheses exactly. The most prominent deviation was that Orange typically did not bid the minimum admissible bid. Bids which exceed the minimum admissible bid are called "jump bids". Orange frequently placed such jump bids. However, the size of its jumps never exceeded 5% of the admissible minimum bid. On average, they bid 2.06% over the minimum admissible bid. These are relatively small jump bids. We discuss possible rationales for jump bids in B"orgers and Dustmann (2001). For example, jump bids might have been placed with the aim of avoiding ties, which occurred quite frequently in the auction. As indicated in B"orgers and Dustmann (2001) the existence of jump bids does not seem to be a very significant deviation from our hypotheses, and therefore we shall not focus on jump bids.

Orange only placed bids for licenses B and E. License A was, of course, not available to Orange. That Orange never bid for licenses C and D is somewhat surprising, but can easily be rationalized within the private value paradigm by assuming that Orange assigned value zero to these licenses. We therefore now focus on licenses B and E.

Because Orange stayed in the auction until the end, its bidding behaviour does not identify the value which it attached to licenses B and E. Orange may well have attached values to these licenses which by far exceeded the final bids for these licenses. We can, however, under the private value and straightforward bidding hypothesis make inferences from Orange's bidding behaviour regarding the *difference* between its value for B and its value for E. To see this denote by  $v_B$  Orange's value for license B and by  $v_E$  their value for license E. Also, denote by  $p_B$  the price of license B and by  $p_E$  the price of license E. Straightforward bidding means that Orange bids for license B if and only if

$$v_B - p_B \geq v_E - p_E \Leftrightarrow \\ p_B - p_E \leq v_B - v_E$$

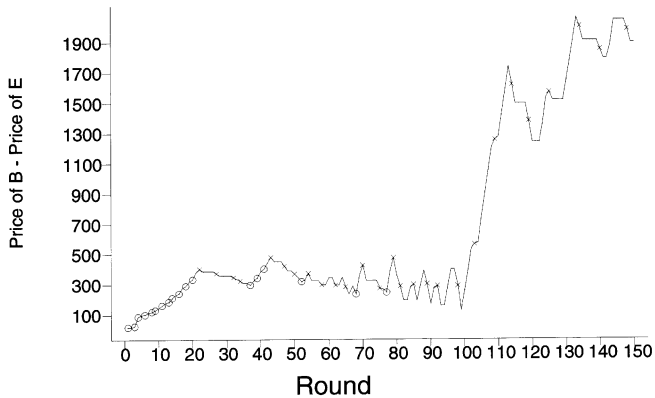
Thus, whenever we observe Orange bid for B in some round, we can deduce that the value difference  $v_B - v_E$  is at least as large as the price difference  $p_B - p_E$  in that period. Similarly, whenever we observe Orange bid for E in some round, we can deduce an upper bound for the value difference.

In figure 2 we show how the price difference  $p_B - p_E$  (in million Pounds) evolved during the 150 rounds of the auction. We have marked each period in which Orange bid for B with a circle and each period in which Orange bid for E with a cross. Under straightforward bidding with private values, a horizontal line through figure 2 which intersects the vertical axis at  $v_B - v_E$  will separate the circles from the crosses. Indeed, under the private value and straightforward bidding hypothesis all circles will be below that line, and all crosses will be above it. This follows from the above inequality. Now, of course, we do not know  $v_B - v_E$ . But we can test in the graph in figure 2 whether bidding behaviour is compatible with our hypothesis by checking whether there exists some horizon-

tal line through figure 2 with the property that all circles are below it and all crosses are above it.

Figure 2

**Oranges Bids for Large and Small Licences**



Bids for small licences: x, bids for large licences: o.

It is easy to see that we can separate circles from crosses in figure 2 by drawing a horizontal line which intersects the vertical axis at roughly £ 270 million. This leaves a few circles above the horizontal line, i.e. a few bids for license B are made although the price difference is larger than this estimate of the value difference. However, the difference between the price difference and the value difference is never very large, at least not in relative terms. Below, we shall find much larger deviations from our benchmark hypothesis. Orange is one of the companies which comes closest to satisfying our benchmark hypothesis.

#### IV. Bidding for License B

We now turn to our case studies. We begin by considering the two main companies which bid for license B. All companies were allowed to bid for this license. However, from round 78 onwards only two companies, Vodafone and BT3G, bid for license B. We shall focus on these two companies. Vodafone and BT3G were at the time of the auction the two largest incumbents in the UK mobile phone market. If they wanted to acquire a large third generation license they had to win license B.

Vodafone's behaviour is easy to describe. They only bid for license B. Moreover they always bid the minimum admissible bid for license B, with two exceptions. In round 123 Vodafone placed a jump bid which exceeded the minimum

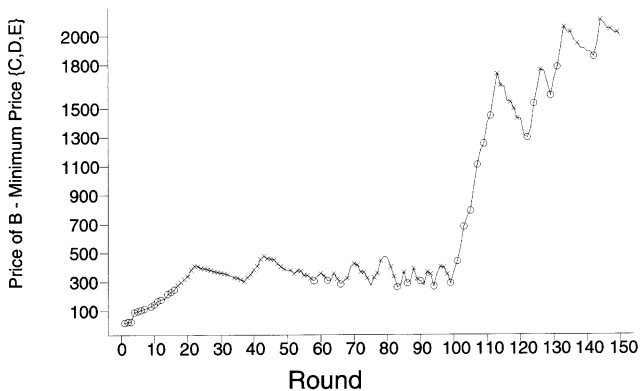
bid by about 1.1%. In round 143 Vodafone placed a jump bid which exceeded the minimum bid by about 1.3%.<sup>12</sup> The latter bid was Vodafone's final bid in the auction. It clinched license B for Vodafone. Note that both jump bids were relatively small, for example they were smaller than the next minimum bid increment. Apart from these two jump bids Vodafone's behaviour is easily explained by the private value and straightforward bidding hypothesis. They might have had a very high value of B, far beyond the price finally achieved in the auction, and a very low value for all other licenses.

Unlike Vodafone, BT3G placed bids on small and on large licenses. When bidding for a small license BT3G always only bid for the cheapest of all small licenses. All bids by BT3G were exactly equal to the lowest admissible bid. These aspects of BT3G's behaviour are thus easily compatible with our hypotheses.

What is less clear is how BT3G chose whether to bid for a large or a small license. We construct in figure 3 a graph for BT3G which is analogous to figure 2 for Orange. Because BT3G always bid for the cheapest of licenses C, D and E we assume that BT3G was indifferent between the three small licenses, and therefore display in figure 2 the difference (in million Pounds) between the price of license B and the *lowest* of the prices of licenses C, D and E. As before we mark bids for a large license by circles and bids for a small license by crosses. It is clear from figure 3 that there is no horizontal line through the graph which would even approximately separate circles from crosses. Thus, there is no consistently revealed valuation of the advantage of having a large rather than a small license.

Figure 3

**BT3G's Bids for Large and Small Licences**



Bids for small licences: x; bids for large licences: o.

<sup>12</sup> Cramton (2001, p.50) writes that "Vodafone often would use jump bids (bids above the minimum bid) to express its resolve in winning the B license." But the claim that jump bids occurred *often* is an error.

### 1. BT3G's Bids in Phase 1

To understand better what happened we consider separately BT3G's behaviour in the three phases of the auction which we defined at the end of Section II. Consider first phase 1. BT3G began by bidding for license B but abandoned bids for B in round 17. In round 16, in which BT3G was still bidding for B, the price difference between B and the small licenses was £ 247.3 million, whereas in round 17, when BT3G bid for a small license, it was £ 277.2. Thus, under the hypothesis of private values and straightforward bidding we would conclude after round 17 that BT3G's estimate of the value difference was between £ 247.3 million and £ 277.2 million. Until and including round 56 BT3G never bid again for license B. This is consistent with the estimate just provided because throughout this period one had to pay more than £ 277.2 million extra to obtain license B rather than a small license.

However, in round 57 BT3G suddenly bid for license B although the price difference was now £ 306.7 million. BT3G then switched frequently between bidding for B and bidding for a small license. If one neglects the earlier bids, and focuses on the bids from round 57 until the end of phase 1, then BT3G's bids revealed that their estimate of the extra value provided by license B in comparison to the smaller licenses was between £ 310.1 million and £ 319.3 million. Thus BT3G's estimate of the extra value seems to have been revised upwards, but possibly only by as little as 12%.

### 2. BT3G's Bids in Phase 3

Before we turn to phase 2 we briefly consider phase 3. In this phase BT3G placed only six bids, and of these only one was for license B. The bid for license B occurred when the difference in price between license B and the small licenses was lowest in phase 3. If we thus consider bidding in phase 3 in isolation, then this was entirely compatible with the private values and straightforward bidding hypothesis. BT3G's bid in round 137 revealed that their estimate of the difference in value between a large and a small license was not more than £ 1,945.1 million, and their bid in round 142 revealed that the estimate was not less than £ 1,854.6 million.<sup>13</sup>

### 3. BT3G's Bids in Phase 2

It is now important to consider in detail what happened in the intermittent phase 2. Figure 3 shows that BT3G raised in three "waves" the amount that it was willing to bid extra to obtain a large rather than a small license. The first such wave began in round 101, the round in which One.Tel withdrew. In that round BT3G placed a bid on license B although the price difference was now £ 440.8 million, and thus above their previous threshold of £ 319.3 million. BT3G

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<sup>13</sup> A value difference in this interval also rationalizes BT3G's six bids in phase 2b except the bid for license C in round 126 when the price difference was only £ 1,762.6 million.

kept bidding for B until and including round 111 in which the price difference had reached £ 1,445.5 million. This is the end of the first wave. BT3G switched back to a small license and bid for a small license even in round 119 although the price difference had now dropped back to £ 1,428.3 million. The second and third waves of BT3G's bidding for license B in phase 2 both consisted only of two bids each. In the second wave (rounds 122 and 124) BT3G was willing to bid for license B until the price difference had reached £ 1,530.8 million, and in the third wave (rounds 129 and 131) BT3G was willing to bid for license B until the price difference had reached £ 1,781.5 million.

#### 4. The Main Questions

The most important deviation of BT3G's behaviour from our benchmark hypothesis is the apparent rise in BT3G's evaluation of the difference between a big and a small license at the beginning of phase 2 of the auction. A second puzzle is why in phase 2 BT3G occasionally did not bid for license B although the price difference had fallen below a level at which BT3G had placed bids for license B before. We now discuss alternatives to our benchmark hypothesis which can explain some of this behaviour.

#### 5. What Caused BT3G to Bid for Large or Small Licenses?

*Bidding in Early Rounds Is Arbitrary.* The simplest explanation of the rise in BT3G's evaluation of the difference between a big and a small license is that bidding in the early rounds was arbitrary, as the number of active bidders exceeded the number of available licenses significantly, and therefore the probability of the auction ending soon was so low that bids weren't really significant. We point out, however, that our data show that BT3G's bidding behaviour in these rounds is remarkably consistent. This suggests that BT3G's behaviour was not arbitrary. Of course, it may have been guided by considerations other than myopic surplus maximisation. We discuss this possibility later.

*Budget constraints:* It seems plausible that companies which participated in the UK auction faced budget constraints. The government had offered successful bidders two options for paying for their licenses: either instantaneous payment after the end of the auction, or deferred payment where 50% had to be paid instantaneously and the remaining 50% plus interest had to be paid over the next five years.<sup>14</sup> Companies seem to have regarded the option of deferred payment as obviously too costly (National Audit Office 2001, p.31). It then seems plausible that the bidders arranged their funding before or during the auction. Apparent changes in bidding strategies during the auction may be due to changes in companies' financial situation.

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<sup>14</sup> Special rules applied to Vodafone and Orange because of the connection created between these two companies by Vodafone's successful takeover of Mannesmann, which owned Orange.

In the case of BT3G the willingness to bid more aggressively for license B from round 101 onwards might be due to the fact that BT3G had arranged additional finance at that time. It had perhaps become clear that more money was needed than had been initially raised. If finance was arranged in round numbers, then it might be relevant that up to round 94 the largest bid by BT3G had been £ 2,339.9 million (in round 94). In round 99 they made their first bid that was above £ 2,5000 million. Thus, up to that point £ 2,5000 million might have been their budget constraint. This argument does not explain BT3G's frequent switching between large and small licenses at the later stages of the auction, but a more complicated financial history might account for that, too.

There is another way in which budget constraints might have affected BT3G's bidding. If the bidders in the auction were subject to budget constraints then each bidder may have had an incentive to drive up the prices which other bidders had to pay, either to weaken these other bidders in subsequent European spectrum auctions, or to make it harder for them to finance the investments needed to offer attractive third generation services in the UK. Thus the primary aim of the bids which BT3G made for license B in phases 2 and 3 of the auction may have been to raise the price which Vodafone had to pay for license B. It may not actually have been BT3G's purpose to win that license themselves. Such a strategy is rational only if BT3G is sufficiently convinced that every bid which it places on license B will be overbid. BT3G might have become convinced of this because, as explained earlier, Vodafone's strategy from the beginning of the auction had been to bid only for license B and to overbid every bid placed on that license. As Cramton (2001, p.50) writes one can interpret Vodafone's behaviour as an expression of "its resolve in winning the B license". This exposed Vodafone to the risk that other companies such as BT3G would place bids on license B solely to raise the price which Vodafone had to pay. On the other hand nobody could ever be completely sure that Vodafone would behave in the future as it had done in the past. The bids placed in the later phases of the auction were very large. BT3G always ran the risk that Vodafone abandoned license B in which case BT3G would most likely be stuck with its bid. This speaks against this theory. We also note that this argument does not explain BT3G's frequent switching between license B and small licenses.

*Social learning:* Companies might have learned from other companies' bidding behaviour about the true value of the licenses for which they were bidding. Since Milgrom and Weber's seminal (1982) paper this effect has received much attention in the auction literature.<sup>15</sup>

In the current auction it seems plausible that some such social learning has taken place. But a priori one would expect this effect to be of minor quantitative importance. Social learning is an important quantitative effect only if some bidders hold private information which is potentially of large commercial significance to other bidders. At the time of the auction there was large uncertainty about the economic value of third generation mobile telephone technology, but

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<sup>15</sup> We use in this paper the phrase "social learning" rather than the more conventional terminology of "common" or "affiliated values" in order to emphasize that what matters is really the informational effect that one firm can learn from other firm's private information by observing its actions.

this uncertainty seems to persist until today. It does not seem plausible that at the time of the auction any one bidder had highly significant private information.

We now turn to the data. A first potential source of information to British Telecom about the added value of holding a large licence were other bidders' bids placed for license B. As we mentioned earlier from round 78 onwards Vodafone was the only other company that bid for license B. It is conceivable that Vodafone's strategy of not bidding for a small license, and its willingness to counter every bid by BT3G for license B, lead BT3G to revise its estimates of the value difference upwards.

BT3G might also have learned about the value difference between a large and a small licence from observing bidding on the other large license A. However, as we argue in the next section, it seems that the acceleration in the price of license A in phase 2 followed that for license B rather than the other way round. Thus, we believe that it is more likely that bidders for license A learned from the bidding for license B than that the bidders for license B learned from the bidding for license A.

BT3G might also have learned about the value difference between a large and a small licence by observing bids placed on the smaller licences. For example, the bids placed by NTL Mobile which we discuss below suggested that NTL Mobile's estimate of the value difference between a large and a small license gradually increased in phase 1 of the auction. Observing this effect might have lead BT3G to revise its own estimate.

The precise quantitative form in which a bidder could learn in the auction from other bidders' behaviour will depend on this bidder's prior beliefs as well as this bidder's beliefs about other bidders' behaviour. It seems hard to find a specification of these beliefs which would explain the suddenness of the change in BT3G's behaviour at the end of round 100 and the size of this change, or which would explain the apparent occasional downward shifts in beliefs in phase 2. We have not explored this issue any further, but the hypothesis seems extremely speculative.

There is another way in which social learning might contribute to an explanation of BT3G's bids. BT3G might have tried to manipulate other companies' learning behaviour. In particular, it might have tried to conceal initially its estimate of the value difference between a large and a small license. One indication that this might have been the case is the fact that the estimate of the value difference between a large and a small license revealed by BT3G's early bids in phase 1 of the auction was very close to that revealed by the other incumbent who bid on large as well as small licenses in that phase, namely Orange. Orange's bidding, though not entirely consistent, suggested that their estimate of the value difference was around £ 270 million. BT3G might have deliberately tried not to deviate from this too much. In the language of game theory, BT3G might have tried to play a "pooling strategy", concealing its true information from the market by behaving like a competitor.

The question arises what BT3G could gain by such a strategy. The purpose might have been to induce other bidders to drop out of the auction. Once that was achieved in round 101, BT3G might have felt ready to place much higher

bids. Thus it appears conceivable that a pooling rationale explains BT3G's strategy. A question then is why other companies did not adopt the same strategy as BT3G. In particular, Vodafone seems to have seen an advantage in exactly the opposite strategy: stating publicly a strong interest in licence B, and never moving away from it. Perhaps Vodafone's managers held different subjective beliefs about the situation.

*Allocative externalities:* Companies' valuation of a license may depend on which other bidders will win a license. If this is the case one speaks of "allocative externalities". The potential importance of allocative externalities for license auctions has been emphasized by Jehiel and Moldovanu (2000; 2001). In the case of the UK auction one might speculate that BT3G's apparent changes in their valuation of license B in comparison to a small license might have been driven by BT3G's expectations of who else would win a license. We investigate now evidence which might show whether this was indeed the case. A problem which we face is that the number of ways in which BT3G's valuation of license B in comparison to a small license might have depended on who else wins a license is very large. We shall focus here on two hypotheses which seem to us particularly plausible a priori.

The first is that BT3G's incentive to acquire a large rather than a small licence might have been affected by how likely it appeared that TIW was going to win license A, as it eventually did. One reason for this might have been that TIW was backed by the financially very strong Hutchison Whampoa group, a former owner of Orange, and BT3G might have been aware of this. BT3G might have viewed TIW as a particularly formidable competitor in the UK market.

To evaluate whether this hypothesis contributes to the explanation of our bidding data we ask whether BT3G revealed a consistent estimate of the value difference between license B and the small licenses if one conditions on whether TIW is the current leader on A. This assumes that BT3G took the current leadership on license A as an indication of who might win license A. The assumption is in line with the myopia assumed in straightforward bidding, but obviously it can be criticized. We see no more plausible alternative to this assumption, though.

It turns out that conditioning on whether TIW is current leader on A does not eliminate the inconsistencies in BT3G's bids. To show this we begin with table 3 which shows the number of bids placed by BT3G on license B and on the small licenses as a function of the event that TIW was the current leader for license A. The data shown are for all rounds. We show in brackets the data for rounds 101-150 only.

Table 3

**BT3G's Bids Conditional on the Leading Bidder for Licences A  
(Data in Brackets Concern Rounds 101-150 only)**

	TIW is current leader on A	TIW is not current leader on A	Total
BT3G bids for B	7 (4)	26 (7)	33 (11)
BT3G bids for C, D or E	11 (10)	63 (2)	74 (12)
Total	18 (14)	89 (9)	107 (23)

The first fact to note is that BT3G placed significant numbers of bids on small licenses in phase 1 of the auction, both when TIW was current leader on A and when TIW was not current leader on A. As a consequence BT3G's bidding in phase 1 of the auction revealed an upper boundary for both conditional value differences which were certainly not larger than the highest price difference in phase 1. Next observe that BT3G placed significant numbers of bids on license B in phase 2, both when TIW was the current leader on A, and when TIW was not the current leader on A. Thus, we obtain lower boundaries for the conditional value differences which are certainly much larger than the upper boundaries in phase 1 (compare figure 3). Thus, the inconsistencies between phase 1 and phases 2 and 3 do not disappear if one conditions on whether TIW is the current leader on A.

One might still hope that the proposed externality concerning the winner of license A could provide an explanation of BT3G's behaviour in phases 2 and 3 only, neglecting phase 1. However, this is not the case. Considering first periods in which TIW was leading on A, we note that the last bid of the first "wave" of bidding for B fell into a period in which TIW was leading on A. All of the immediately following bids for a small license except the first one were also made when TIW was leading on A. As figure 3 indicates this implies that there is no conditional estimate of the value difference which could rationalize BT3G's bids. Considering next periods in which companies other than TIW were leading on A we note that in round 113 BT3G bid for a small license, thus providing us with an upper boundary for the conditional value difference of £ 1,733.6 million, but in round 131 BT3G bid for license B, thus providing us with a lower boundary for the conditional value difference of £ 1,71.5 million. Thus, there is again no consistent conditional value difference.

The second possibility which we have investigated is that the anticipated number of other incumbents acquiring a license might have been a factor. BT3G began bidding aggressively for license B when four bidders had left the auction and a fifth had asked for a waiver round. At that stage it seemed more likely that more incumbents would hold licenses, and this might have triggered for some reason an increase in the extra value which BT3G attached to a large license in comparison to a small license. The beginning of the second "wave" of BT3G's bids for B followed similarly immediately after Worldcom withdrew in round 121.

However, the beginning of the third “wave” is not associated with any withdrawal, and instead the end of the third “wave” coincides with Telefonica’s withdrawal from the auction in round 133.

An alternative way of looking at this issue is to regard the current number of incumbents who are leading bidders on a license as a predictor of the number of incumbents who will ultimately win a license, and to ask whether conditional on this predictor BT3G revealed consistent estimates of the value differences. Table 4 shows the frequency of bids by BT3G on license B as a function of the number of incumbents leading on a license. We have made one correction in this table, though. We have not counted an incumbent as leading bidder on a license if the bid that BT3G was about to place displaced that leading bidder. Suppose, for example, that incumbents were leading on B, C and E, and that BT3G was about to bid for B. Then we counted this as a bid for B with two (not three) incumbents leading on other licenses, because BT3G knew that it would displace the leader on B from his position. Like in table 3 information which relates only to rounds 101-150 is indicated in brackets.

Table 4 indicates that trivially there will be conditional value differences which rationalize BT3G’s bids if we condition on the event that zero incumbents are leading on B, C, D and E. In this event BT3G never bid for B. Table 4 also seems to indicate that we can obtain a conditional value difference for the case that 3 incumbents are leading on B, C, D and E. In this case BT3G never bid for B. For the intermediate cases an argument similar to the one we used earlier in the context of table 3 suggests that there is no conditional value difference which rationalizes bids across phases 1, 2 and 3. We could consider phases 2 and 3 in isolation, but a simple analysis shows that this does not affect the conclusion.

Table 4

**BT3G’s Bids Conditional on the Number of Leading Incumbents  
(Data in Brackets Concern Rounds 101-150 only)**

	0 incumbents leading on B, C, D or E	1 incumbent leading on B, C, D or E	2 incumbents leading on B, C, D or E	3 incumbents leading on B, C, D or E	Total
Bids for B	14 (0)	10 (4)	9 (7)	0 (0)	3 (11)
Bids for C, D or E	0 (0)	36 (2)	34 (6)	4 (4)	74 (12)
Total	14 (0)	46 (6)	43 (13)	4 (4)	107 (23)

*Shareholders’ Opinion:* Bidders in the auction are likely to have monitored carefully the views of their shareholders. These views might have expressed themselves in share prices. Managers might, for example, have found that the share price responded very negatively to particular bids, and might have avoided such bids in the future. Table 5 shows British Telecom’s, and, for comparison purposes, also Vodafone’s share prices at the London Stock Exchange

on three crucial dates: on the last trading day before the auction began, on the last trading day before phase 2 of the auction began, and on the last day of the auction. In brackets we indicate the change in comparison to the share price on the last trading day before the auction began.<sup>16</sup> The table indicates that British Telecom's share price seemed to suffer more than that of Vodafone at the end of phase 1 of the auction. When the auction was over British Telecom's share price had recaptured some of its losses whereas Vodafone's share price had gone down further.

Table 5

**BT and Vodafone Share Prices in £s**

	Share price before round 1 (3 March)	Share price before round 99 (4 April)	Share price after round 150 (27 April)
British Telekom	1169.98	995.91 (-16%)	1016.44 (-13%)
Vodafone	369.5	321.5 (-13%)	279.25 (-24%)

One might argue that the stock market signalled to BT3G that its bidding in phase 1 was too conservative, and BT3G's more aggressive bidding in phases 2 and 3 might have lead to the recovery in its share prices. A cross company comparison for phases 2 and 3 suggests the reverse effect, though. The more aggressive bidder, Vodafone, suffered losses, whereas the less aggressive bidder, British Telecom, gained.

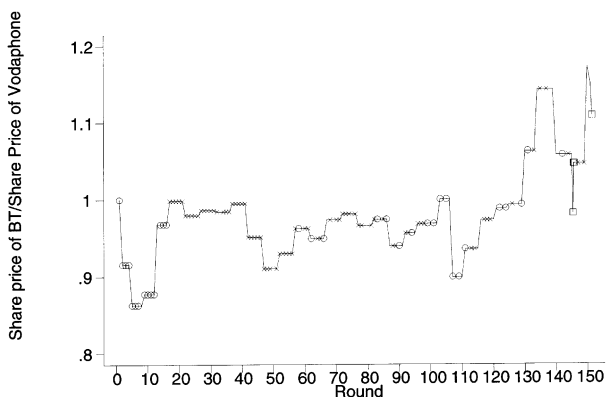
Table 5 hides large volatility in share prices. In figure 4 we show the ratio of BT3G's and Vodafone's share price at the London Stock Exchange. The purpose of considering this ratio is to keep track of the relative stock market success of the two companies. We have normalized the ratio to equal 1 on the last trading day before the auction (3 March 2000). For each round we indicate the value of the share price ratio on the preceding trading day.

Figure 4 confirms that British Telecom did worse than Vodafone in phase 1, and the figure hints at the effect that bids for small licenses lead to downward movements in the ratio whereas bids for large licenses lead to upward movements. However, BT3G's more aggressive bidding for B in phase 2 initially lead to a dramatic fall in the share price ratio, and if BT3G had kept track of this one might have expected them to abandon this strategy earlier than they actually did. Considering phases 2 and 3 overall there does not seem to be any predictable effect of bids for B on the share price ratio.

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<sup>16</sup> The source for the share price information in table 4 and figure 4 is Datastream.

Figure 4

**Ratio of British Telekom and Vodafone's Share Prices**

BT3G's bids for small licences: x; BT3G's bids for large licences: o;  
 days on which the London Stock Exchange traded but the auction  
 didn't take place: ·

*Management disagreements:* Shifts in a company's bidding strategy may also be due to changing power structures in that company's management. Thus BT3G's more aggressive bidding for a large licence from period 101 onwards may be due to the fact that a different group in its management won control of the bidding strategy. An indicator that there was a potential for disagreement is that Sir Christopher Bland, when becoming new chairman of British Telecom in April 2001, commented that in his opinion the company "should never have bid for a third-generation telephone licence" (Independent on Sunday 2001). The "Independent on Sunday" added: "However, he is not critical of BT's board for bidding for a licence: 'Hindsight is a wonderful thing.'" It is, however, hard to conceive of an ongoing power struggle which would induce BT3G to switch back and forth between small and large licenses as they did in the auction.

## 6. Summary

We find little direct evidence for any of the hypotheses which we consider. However, the most plausible speculations seem to be that BT3G's initial reluctance to bid for license B was either due to budget constraints, or a deliberate strategy to conceal its true valuation of license B. Behaviour throughout the auction may also have been affected by management disagreements.

## V. Bidding for License A

The leading bidders for license A were TIW and NTL Mobile. Both bidders participated in the auction until its end. TIW ultimately won license A, and it was NTL Mobile's decision to withdraw from the auction in round 150 which triggered the end of the auction. We conclude that these two companies were the leading contenders for license A because after round 108 there was only one bid from another bidder for license A, namely the bid by Worldcom in round 116. In round 108 the price of license A had reached £ 3,000 million. At the end of the auction it was £ 4,384.7 million. Thus, there was a significant price increase, and it was largely due to these two contenders' bids.

The bidding competition between TIW and NTL Mobile for license A took place in phase 2 of the auction. It was settled by the end of phase 2 in round 133. At that stage TIW was the leading bidder for license A, and its position was not challenged any further in phase 3. Note, however, that NTL Mobile made some bids for small licenses in phase 3.

As outsiders to the UK mobile telephone market TIW and NTL Mobile were allowed to bid for licenses A and B when bidding for a large license. However, license A was somewhat larger than license B, and it was also for most of the auction cheaper than license B. There were only 15 rounds in which license A was more expensive than license B. The last such round was round 76. The largest difference in price was £ 77.6 million, which is less than 2% of the final price of licence A. All this seems to suggest that almost always A was the better deal than B. We do indeed find that NTL Mobile never bid for license B. TIW is one of the few outsiders who did place bids on licence B. However, all bids by TIW for license B occurred very early in the auction. From round 14 onwards, TIW did not bid for licence B again.

If we neglect TIW's early bids for B we can simplify the argument, and assume that TIW and NTL Mobile faced a choice between bidding for the large licence A and bidding for one of the smaller licenses C, D or E. When choosing for which of licenses C, D or E to bid, both companies did not necessarily choose the cheapest of these licenses. This suggests that they might have had preferences over these apparently very similar licenses. In our companion paper (Börgers and Dustmann 2001) we use a random utility model to estimate the value differences. Our estimates suggested that NTL Mobile ranked licenses in alphabetical order: C, D and E, whereas TIW ranked them in reverse alphabetical order: E, D, and C. However, none of the estimated value differences was significantly different from zero. Moreover, as the prices of licenses C, D and E stayed very close together, as can be seen in figure 1, this is not a major issue. To simplify our arguments we shall work with the assumption that TIW and NTL Mobile were indifferent between licenses C, D and E.

Both TIW and NTL Mobile deviated from the rules of straightforward bidding, and did not always bid the minimum bid. If we ignore for TIW their somewhat erratic bids in round 1-13, then we find that 30% of TIW's bids were jump bids. For NTL Mobile the percentage of jump bids is 32%. The average size of TIW's jump bids after round 13 was 2.1% above the required minimum bid, and the average size of NTL Mobile's jump bids was 1.96% above the minimum bid. As

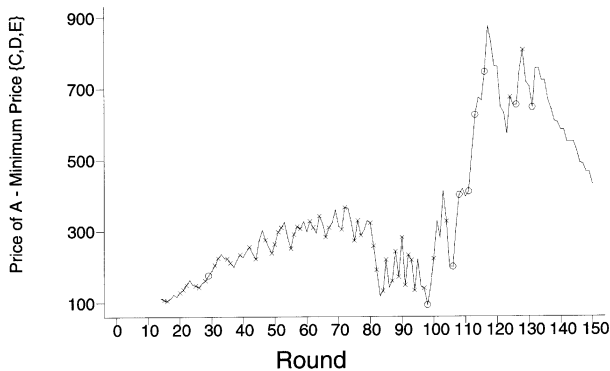
before, we argue that the jump bids are relatively small, and a minor deviation from our hypotheses.

The final and most important step of our analysis is to consider how TIW and NTL Mobile chose whether to bid for a large or a small license. Figures 5 and 6 describe these choices. The figures are analogous to figures 2 and 3 which referred to Orange and BT3G. The figures indicate that neither of the two companies placed their bids in accordance with the hypothesis of straightforward bidding under private values. As was the case with BT3G we regard these deviations from the straightforward bidding hypothesis as the most important deviations, and therefore focus on them in this section.

We begin our discussion with TIW. Recall that TIW was leading bidder on license A at the end of phase 2, and was not further challenged in that position in phase 3. Therefore we can restrict attention to phases 1 and 2.

Figure 5

### TIW's Bids for Large and Small Licences



Bids for small licences: x, bids for large licences: o.

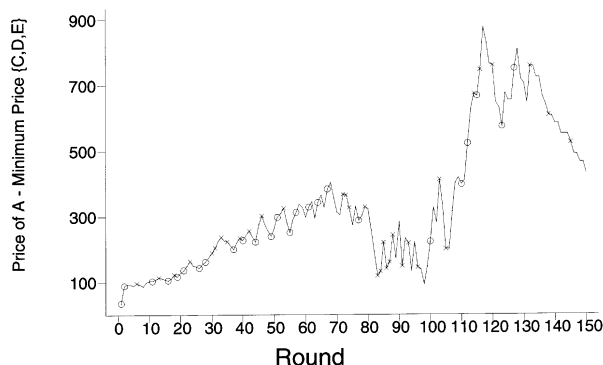
#### 1. TIW's Bids in Phase 1

Note that figure 5 ignores rounds 1-13 because in these rounds TIW placed bids on license B which are hard to explain, as we discussed above. In the subsequent rounds of phase 1 TIW only made two further bids for license A. One was in round 29 when the price difference was £ 176.2 million. The second was in round 98 when the price difference was £ 92.8 million. The bid in round 29 is puzzling because in later rounds the price difference was much lower, yet TIW did not bid for license A. The second bid is easier to understand because it was made when the price difference was lower than it had been in any round since

round 9. Thus we treat the bid in round 29 as an outlier, and deduce that TIW's revealed extra value attached to license A in comparison to a small license was between £ 92.8 million (the price difference in round 98) and £ 107.7 million (the price difference in round 14).

Figure 6

**NTL Mobile's Bids for Large and Small Licences**



Bids for small licences: x, bids for large licences: o.

**2. TIW's Bids in Phase 2**

TIW's first bid in phase 2 was a bid for license D in round 104. This bid was entirely consistent with their behaviour in phase 1. However, in round 106 they suddenly started to bid for license A again. At this stage the price difference between A and the small licenses was £ 200.2 million, a difference which in phase 1 they would have regarded as prohibitive. TIW continued with four further bids for license A. The last of these bids, in round 116, was at a price difference of £ 745.4 million. Like in the case of BT3G we find that in the early rounds of phase 2 there was apparently a sudden and dramatic revision upwards in TIW's estimate of the extra value of a large license.

TIW's four further bids in the auction are somewhat surprising because they suggest a downward revision of the estimate of the difference. In round 124, when the price difference had dropped to £ 674.7 million TIW refused to bid for A and instead bid for E. In round 126, when the price difference was £ 653.2 million, TIW returned to licence A. Thus it seemed that their estimated value difference was now between £ 653.2 million and £ 674.7 million. The final two bids by TIW were compatible with this estimated value difference. This value difference thus rationalizes all bids by TIW in phase 2b of the auction.

### 3. NTL Mobile's Bids in Phase 1

NTL Mobile in phase 1 gradually moved its revealed estimate of the extra value of holding large license A upwards. For example, in round 1 NTL Mobile bid for license A when the price difference was only £ 35.7 million. In round 2 it was willing to bid again for license A although now the price difference had gone up to £ 89.2 million. This second bid was the highest bid in its round and NTL Mobile entered rounds 3, 4 and 5 as the leading bidder for license A. In round 5 it was overbid by another bidder. In round 6, when the price difference between license A and the small licenses had reached £ 96.8 million, NTL Mobile decided not to bid for A again, but to switch to C. At this stage it seemed that NTL Mobile's estimate of the added value of a large license in comparison to a small license had been pinned down quite precisely. However, shortly afterwards, in round 11, when the price difference was £ 103.7 million, NTL Mobile bid again for A. In round 13 when the price difference had gone up to £ 114.2 million NTL Mobile abandoned A again. At that stage NTL Mobile's evaluations seemed to have been narrowed down again, except that in round 19, when the price difference was £ 116.6 million, NTL Mobile returned to license A. This pattern continued until round 68 when NTL Mobile bid for license A at a price difference of £ 402.4 million.

There was then a break in NTL Mobile's behaviour. For the rest of phase 1 of the auction NTL Mobile bid only one more time for license A although the price difference between license A and the smaller licenses fell considerably. NTL Mobile was not even willing to bid for license A in round 83 when the price difference had fallen back to £ 118.8 million. The one bid which it did make for license A is hard to explain. It was made at a price difference of £ 287.5 million in round 77.

### 4. NTL Mobile's Bids in Phase 2

Phase 2 of the auction began in NTL Mobile's case really in 100. At that stage four firms had withdrawn, and One.Tel had asked for a "waiver". These waivers had turned out to be advance indicators of the withdrawal of a bidder. In phase 2 NTL Mobile began to bid much more aggressively for license A. We can distinguish three "waves", although the first and third wave are relatively short. NTL Mobile began bidding for license A at a price difference of £ 222.5 million in round 100. It abandoned license A though in round 103 when the price difference went up to £ 411.6 million and wasn't even willing to bid for A in round 105 when the price difference had fallen to £ 200.2 million. In round 110 a second "wave" started, and NTL Mobile returned to license A at a price difference of £ 396.9 million, and was willing to bid for license A even at much higher price differences. In fact, the next seven bids of NTL Mobile can all be rationalized by postulating a value difference between £ 666.1 million and £ 673.1 million. NTL

Mobile concluded phase 2 with a surprising bid for license A in round 127 when the price difference had gone up to £ 749.2 million.<sup>17</sup>

### 5. NTL Mobile's Bids in Phase 3

NTL Mobile did not bid for license A at all in phase 3 but instead bid three times for a small license. This is surprising because TIW entered this phase as the leading bidder for license A and was not challenged any further in that position. As a consequence the price difference between license A and the small licenses dropped in phase 3, and was only £ 381.1 million at the end of the auction. Despite of this drop in the price difference NTL Mobile did not return to bidding for A.

### 6. The Main Questions

As in the case of BT3G in the previous section the most important issue is probably: "What lead TIW and NTL Mobile to bid so much more aggressively for a large license after the end of phase 1?" In the case of NTL Mobile we have, however, additional interesting questions: What caused the gradual increase in NTL Mobile's estimate of the value difference in the early part of phase 1? What caused NTL Mobile to abandon bidding for license A in the late part of phase 1? Why did NTL Mobile not bid for license A in phase 3? We now investigate whether the ideas which were introduced in the previous section can contribute to answers to these four questions.

### 7. TIW's and NTL Mobile's Bids: Some Explanations

*Bidding in Early Rounds Is Arbitrary.* The break between phase 1 and later phases is easiest explained by arguing that bids in phase 1 were placed in arbitrary ways because it was unlikely that the auction would close soon. As indicated above we do indeed find that TIW's bids in rounds 1-13 are hard to rationalize, and those bids might be regarded as arbitrary. TIW's choices in rounds 14-100 do not seem arbitrary, however. Indeed, TIW systematically avoided bidding for A.

Unlike TIW, NTL Mobile made bids for license A throughout the first 100 periods. Its behaviour does not appear to be arbitrary, but it seems to reveal a gradually increasing value difference between license A and the small licenses.

To dismiss early bids for A as arbitrary one would, moreover, have to argue that the fact that many bidders were still left in the auction implied that bids for

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<sup>17</sup> Considering phases 2a and 2b separately does not add much insight into NTL Mobile's behaviour. In phase 2b they placed only two bids. Both were for A. One of them was compatible with the earlier revealed price difference, and the second one was the one in round 127 to which we refer in the main text.

license A were almost certain to be overbid by some other bidder. However, for license A, unlike for license B, there was no bidder who was clearly determined to win the license. Thus, any bid that was placed on license A seemed to run a risk of being the last bid for that license.

*Budget Constraints:* Could budget constraints explain TIW's decision to place so few bids for license A in the first phase of the auction? We argue that this is not a plausible explanation. The highest bid which TIW placed in the first phase was a bid of £ 2,339.1 million for license D in round 100. In all rounds up to round 98 a budget of this size would have permitted TIW also to bid for license A.

The impact of budget constraints appears to be more interesting in the case of NTL Mobile. NTL Mobile twice ceased to bid for license A in a somewhat unexpected manner. The first instance followed round 77 in which NTL Mobile became leading bidder for license A. When NTL Mobile was overbid by Worldcom in round 79<sup>18</sup>, NTL Mobile refused to counter. The minimum admissible bid for license A in round 79 was £ 1,601.9 million. NTL Mobile bid instead for the smaller license D at £ 1,343.5 million. It then continued bidding for the smaller license for a while even though the price difference between a large and a small license had by now fallen. One might think that this was due to budget constraints. However, already in round 86 NTL Mobile was able to bid £ 1637.2 million for license D which was more than had been necessary for license A in round 79. Thus, we believe that it is unlikely that NTL Mobile's abandonment of license A in phase 1 was due to budget constraints.

NTL Mobile's last bid for license A was in round 127 when it bid £ 4,277.7 million. This bid was overbid by TIW in round 131. NTL Mobile did not bid again for license A, nor did any other bidder. To overbid TIW NTL Mobile would have had to bid £ 4,494.4 million. NTL Mobile instead bid for smaller licenses, with its highest subsequent bid being £ 3,970.5 million. Thus it may well have been that NTL Mobile had a budget constraint of, say, £ 4,300 million, and that this was the reason why it did not continue to bid for A. Thus, we conclude that budget constraints may provide a plausible explanation for NTL Mobile's second, although not for its first abandonment of license A.

As explained in the previous section the existence of budget constraints introduces an additional bidding motive into auctions: bidders might place bids to raise the price which their competitors have to pay, with the intention of weakening the competitors in future interactions. One might speculate in this way that NTL Mobile placed its last bids for license A without serious intention of buying license A, but instead to raise the price which TIW had to pay. The owners of NTL Mobile, NTL and France Telecom, might have anticipated that one of them would acquire a license through a takeover, as France Telecom indeed did, and that therefore they had an incentive to financially weaken a potential competitor, TIW. If this strategy was pursued it was very risky, because bids for A always

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<sup>18</sup> We focus at this point on round 77 rather than round 68, which we emphasized earlier, because for the question whether a budget constraint was effective only the very last bid for A in phase 1 matters.

seemed to run the risk of being the last bid for A, and therefore could not be placed spuriously. We therefore do not attach much weight to this hypothesis.

*Social Learning:* TIW and NTL Mobile were both outsiders to the UK mobile telephone market. This suggests that more established firms might have had better information about the chances of third generation technology in the United Kingdom, and that TIW and NTL Mobile tried to deduce other firms' information from these firms' bidding behaviour. We begin by considering whether this hypothesis can help to explain the apparent sudden increase in phase 2 of both companies' estimates of the additional value of a large license in comparison to a small license. In this context it seems interesting that bidding for A lagged a little bit behind bidding for B. For example, the unexpectedly high bids for license B which we have identified in the previous section were placed from round 101 onwards. We find that unexpectedly high bids for license A began to be placed from round 106 onwards. Bidding on license B ceased for a while between rounds 113 and round 121. Similarly, no new bid was made for license A between rounds 117 and 122. Bidding for license B ceased again between rounds 126 and 128. Similarly bidding for A stopped between 128 and 130. Thus, one might speculate that the outsiders who bid for license A learned from the insider bids placed on license B that the difference in value between a large and a small license was larger than they had originally thought. It is surprising, however, that outsiders were ready to revise their initial beliefs so quickly, and to such a large extent.

As in the case of BT3G we might also speculate that TIW tried to "hide" its true valuation of a large license in the early rounds of the auction, and that its purpose was to manipulate the learning of other firms. However, this speculation is hard to reconcile with the fact that TIW placed some aggressive jump bids for licenses A and B in the very first rounds of the auction.

Social learning might be an explanation of the apparent rise in NTL Mobile's estimate of the value difference in the first 68 rounds of the auction. NTL Mobile might have observed other companies' willingness to bid for a large license and it might have revised its own estimate of the value difference in the light of what it observed. However, it is hard to see why this effect abruptly stopped after round 68.

*Allocative Externalities:* TIW and NTL Mobile's valuation of the difference between a large and a small license may have been a function of which other companies seemed likely to win a license. We begin by examining whether TIW's willingness to bid for license A rather than a small license was a function of which company was the currently leading bidder for the other large license, license B. Table 6 shows the number of TIW's bids for license A and small licenses depending on whether Vodafone, BT3G or some other company was the currently leading bidder for B. We ignore rounds 1-13 for the reasons explained earlier.

We interpret table 6 in conjunction with figure 5. Consider first the event that Vodafone is the current leader on B. The fact that conditional on this event TIW placed bids both on license A and on small licenses, both in the first 105 rounds and also in the subsequent rounds, immediately implies that there is no value

difference which could rationalize TIW's bids across the different phases of the auction. The same conclusion can easily be obtained by inspection of table 6 and figure 5 for the event that BT3G was current leader on B. For the event that a company other than Vodafone or BT3G is current leader on B we observe bids by TIW only in the first 105 rounds of the auction, not later. Therefore, this case is not relevant to our discussion here.

Table 6

**TIW's Bids Conditional on the Leading Bidder for B  
(Data in Brackets Concern Rounds 106-150 only)**

	Vodafone is current leader on B	BT3G is current leader on B	Other current leader on B	Total
TIW bids for A	7 (5)	2 (2)	0 (0)	9 (7)
TIW bids for C, D or E	42 (2)	6 (0)	4 (0)	52 (2)
Total	49 (7)	8 (2)	4 (0)	61 (9)

We have also investigated whether conditioning on the total number of incumbents leading on any license might allow us to find value differences which rationalize TIW's bids. However, as in the case of BT3G, this is not the case. We omit the details. Our conclusion is that there is no evidence that TIW's bids were affected by allocative externalities.

We next turn to the question whether allocative externalities might have affected NTL Mobile's bids. The potential externalities which we discuss are again firstly whether the current leader on license B might affect whether NTL Mobile bids for a large or a small license, and secondly whether the total number of incumbents leading on any license might affect NTL Mobile's decision. If our primary interest is in explaining the escalation in bids for a large license from round 100 onwards then the picture is similar to the picture in the case of TIW. We find no evidence that externalities can contribute to an explanation of NTL Mobile's choices. We omit the details.

This leaves the question whether allocative externalities might contribute to an explanation of NTL Mobile's behaviour if we restrict attention to either phase 1, or to phases 2 and 3. We do not have any positive results to report concerning phase 1. As regards phases 2 and 3 one might argue that in phase 3 it had become clear that Vodafone was the most likely winner of license B, and that the number of incumbents holding a license would most likely be 4. Perhaps NTL Mobile abandoned bids for license A in phase 3 because it judged the added advantage of a large license over a small license to be relatively small in an environment with this sort of competition. To explain the data, however, the size of this effect must be larger than seems intuitively plausible.

*Shareholders' Opinion:* We consider first whether TIW's bidding in the auction might have been influenced by trading in their shares. We focus on trading of TIW at New York's NASDAQ stock exchange where TIW is traded as TIWI. Table 7 indicates TIW's share price at four important moments: before the auction, at the end of the phase in which TIW had not shown strong interest in a large license (i.e. on the last trading day before round 106), after round 116 in which TIW bid for license A and the difference between license A's price and the small licenses' price was maximum among all rounds in which TIW bid for A, and finally at the end of the auction. To have a standard of comparison we also list NASDAQ's telecommunications index for these dates. TIW is one of the companies included in this index.<sup>19</sup>

One might argue that the fact that TIW's shares lost more than the telecommunications index in the first phase of the auction triggered a change in TIW's bidding strategy. However, as in the case of BT3G, we find that the evidence for this is very weak. The difference between the performance of TIW's shares and the telecommunications index does not appear to be dramatic. On the other hand, TIW's aggressive bidding for license A between round 106 and 116 went along with a very steep decline in TIW's share price. Yet, even after this period TIW placed bids for license A. Thus, we conclude that there is no strong evidence in favor of the claim that TIW's bidding behaviour was influenced by the performance of its share price.

Table 7

**TIW's Share Price (in US-Dollar)**

	Share price before round 1 (3 March)	Share price before round 106 (5 April)	Share price after round 116 (12 April)	Share price after round 150 (27 April)
TIW for B	239.688	176.25 (-26%)	141.25 (-41%)	146.875 (-39%)
NASDAQ Telekom Index	1178.5	946.44 (-20%)	867.9 (-26%)	792.17 (-33%)

We now consider NTL Mobile. This company was jointly owned by NTL and by France Telecom. The joint ownership makes it less likely that we can find direct relationships between bids and share prices. Nevertheless we briefly consider the share prices of the companies involved. We indicate in Table 8 the share prices of NTL as traded on New York's Stock Exchange (NYSE) and of France Telecom as traded at the Paris Bourse (now part of the Euronext stock exchange). We indicate these prices before and after the auction and also for three other important dates: after round 68 when NTL Mobile abandoned bidding for license A for a while, before round 100 when NTL Mobile resumed bid-

<sup>19</sup> The source for the information in table 7 is [www.nasdaq.com](http://www.nasdaq.com). We indicate daily closing prices.

ding for license A, and again after the end of round 127 when NTL Mobile abandoned bidding for license A a second time.<sup>20</sup>

Table 8

**NTL's and France Telecom's Share Prices (in US-Dollar and euro)**

	Share price before round 1 (3 March)	Share price after round 68 (27 March)	Share price before round 100 (4 April)	Share price after round 127 (14 April)	Share price after round 150 (27 April)
NTL	96.06	101 (+5%)	85.56 (-11%)	72.25 (-25%)	75.88 (-22%)
France Telecom	215.5	195.5 (-10%)	162.1 (-25%)	155.0 (-28%)	163.0 (-24%)

The stock exchange's response to NTL Mobile's initial bidding strategy does not seem to have been particularly negative. Indeed, NTL's initial performance is the best among all companies considered in this paper in the comparable period. Thus, we cannot argue that NTL Mobile's initial change of strategy would have been triggered by negative share price developments. Abandoning the large license seems to have been accompanied by a much larger and sharp fall in share prices. So, we cannot rule out that NTL Mobile resumed bidding for license A in response to the large drop in the share prices of its constituent companies. The more aggressive bidding for license A was accompanied by a large drop in NTL's shares, but by a very modest reduction in France Telecom's shares. It is hard to see in this any explanation of the fact that NTL Mobile abandoned bidding for license A at the end of phase 2. We conclude that share price movements might contribute to an explanation of why NTL Mobile resumed bidding for license A in round 100 but they do not help us to understand better the other aspects of NTL Mobile's behaviour.

*Management Disagreements:* Unlike in the case of British Telecom we have no direct evidence of the possibility of disagreements among the managers considered in this section. However, the fact that NTL Mobile had two owners, NTL and France Telecom, may be a significant factor. One reason why these owners' interests might not have been completely aligned may be that they had different plans for the period after the auction. France Telecom may already have anticipated during the auction that it might take over a company owning a UK license rather than buying on itself, whereas NTL may not have had any such plans. A company which was considering to later buy a successful bidder may have been concerned not to reveal its evaluation of a license in the auction, unlike a company which did not consider such a move. The precise way in which such disagreements might have affected bidding is, however, unclear.

<sup>20</sup> The source for NTL's share price is Datastream. The source for France Telecom's share price is www.euronext.com. We indicate daily closing prices.

## 8. Summary

As in the previous section we find little direct evidence for any of the hypotheses which we consider. However, plausible speculations are that social learning might explain the gradual rise in NTL Mobile's bids for license A in the first periods of the auction, and the sudden rise in TIW and NTL Mobile's bids for license A in phase 2 of the auction. Budget constraints might provide an explanation for NTL Mobile's abandonment of license A in phase 3. We have not found any plausible explanation of why NTL Mobile ceased to bid for license A in phase 1 after round 68.

## VI. Conclusion

This paper, together with its companion paper Börgers and Dustmann (2001), provides a relatively complete analysis of the bids placed in the United Kingdom's spectrum auction. Our purpose in conducting this analysis was to establish whether the bids placed in the United Kingdom's auction can be explained as rational bids for carefully derived valuations of the licenses, or whether the bids placed in this auction can only be interpreted as the result of "bidding fever". We conclude from the data that it is certainly not trivial to rationalise the bidding behaviour that has been observed. Where the data could provide hard evidence for some rationalisations, they refuse to do so. However, there are plausibility considerations which cannot be directly confirmed or rejected by the data, and which rationalise some of the bids which we have seen. Further evidence in similar auctions is needed if a better understanding of bidder behaviour in license auctions is to be achieved. A well founded judgement about the reliability of license auctions in achieving efficient allocations can be formed only once our understanding of bidder behaviour has improved.

## Summary

This paper considers bidder behaviour in the United Kingdom's UMTS spectrum auction. Evidence is reviewed which shows that some bidders in this auction did not bid straightforwardly in accordance with fixed valuations of the licenses. We go on to consider more speculative hypotheses about bidders' behaviour, such as the hypotheses that bidders revised their valuations in the light of other bidders' behaviour, or that bidders' valuations of licenses depended on which other companies appeared likely to win a license. We find weak evidence in favor of some of these hypotheses, but no hypothesis is supported by strong direct evidence. We conclude that the rationalization of bidding in the United Kingdom's UMTS auction remains problematic. As a consequence we are cautious regarding the success of the auction in achieving an efficient allocation of licenses.

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