Some Observations on the German 3G Telecom Auction: Comments on Grimm, Riedel and Wolfstetter

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in:

ifo Studien

Zeitschrift für empirische Wirtschaftsforschung

Jg. 48, Nr. 1, 2002, S. 145 - 156

2002

ifo Studien ISSN 0018-9731

Herausgeber: Prof. Dr. Gerhard Illing
Schriftleitung: Dr. Marga Jennewein

Verlag:
ifo Institut für Wirtschaftsforschung
Poschingerstr. 5, 81679 München
Tel. +49-89-9224-0 www.ifo.de

Some Observations on the German 3G Telecom Auction: Comments on Grimm, Riedel and Wolfstetter*

By *Paul Klemperer*

Contents

Grimm, Riedel and Wolfstetter (2002) have developed an intriguing explanation for the apparently puzzling bidding in the year 2000 German 3G telecom auction. These comments on their paper discuss why I do not find their explanation fully satisfactory, and suggest alternative explanations, including a relative-performance-maximising theory. I also comment briefly on issues about several other 3G auctions.

I. Introduction

The German 3G spectrum auction was undoubtedly a success from the government's viewpoint. Indeed, it was probably one of only three successes among the nine western European 3G auctions. The measure of success most commonly used is total revenue raised per capita, with some adjustments for the level of the telecoms stock index as a reflection of sentiment towards 3G's pros-

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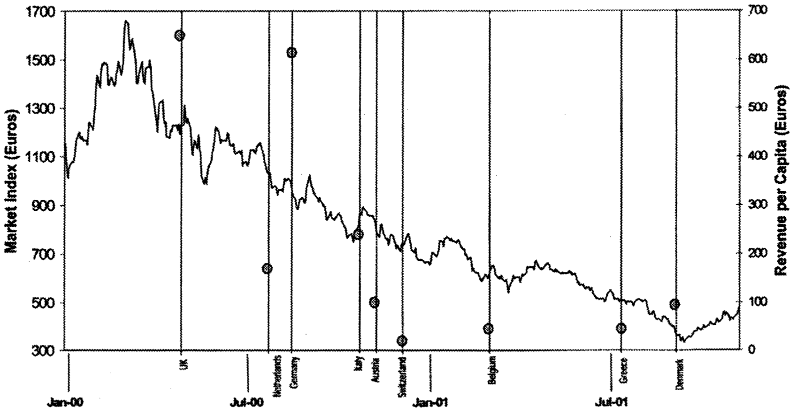
* Acknowledgements: I was the principal auction theorist advising the UK government's Radiocommunications Agency, which designed and ran the UK mobile-phone license auction, but the views expressed in this paper are mine alone. I do not intend to suggest that any of the behaviour discussed below violates any applicable rules or laws. I am grateful for comments from *Elmar Wolfstetter* and to the representatives of the firms involved in the German auction to whom I showed an earlier draft, and I am also very grateful to *Marco Pagnozzi* for our collaboration in the study of the 3G auctions, and for his helpful suggestions about this essay.

pects.[1] (We assume governments have no ability to time the market, and therefore deserve neither credit nor blame for selling when market sentiment is unusually positive or negative.) Based on this, the figure suggests the UK, German and Danish auctions were successes, while the Netherlands, Austrian and Swiss auctions were the biggest failures.

Figure

European 2000-2001 3G Mobile Spectrum Auctions



Note: Per-capita revenues, by country o (right-hand scale);
(auctions are shown on the dates at which they finished);
Dow Jones European Telecom Stock Price Index (left-hand scale).

To be sure, the figure flatters larger countries (especially Germany, conversely it underrates tiny Denmark), flatters centrally located countries (Germany, again, and also Austria and Switzerland), flatters countries with lightly regulated telecom industries (Germany, again, among others) – since larger, centrally located, lightly regulated markets are worth more – but it also ignores the fact that Germany and Austria sold more licences than other countries, reducing the total profitability of those markets. However, the more systematic discussion of the relative performance of the different auctions in Klemperer (2002a) comes to very similar conclusions.

So, since the German auction was both a success and was of a novel and complex design, it clearly deserves study, and Grimm, Riedel and Wolfstetter's

[1] Although efficiency was generally the primary objective, there is no evidence that efficiency differed much across the different countries' auctions. Hence the focus on revenues.

(2002) paper (henceforth GRW) would be welcome for that reason alone; their paper gives very valuable detail about the auction and will be a key reference for anyone studying it. But more than that, the paper is extremely interesting and makes acute observations about both the German and other 3G auctions.

I have learned a lot from the paper, and agree with much of it. However, these comments will naturally focus on the disagreements. Section II summarises why I think GRW's explanation of the bidding in the German auction is not fully satisfactory, and Section III develops this point more fully (the latter section can be omitted by readers who do not want too much detail). Section IV suggests other explanations for the bidding, and Section V develops a relative-performance-maximising theory for it. Sections VI and VII briefly comment on some other 3G auctions, and stress (as GRW also do) the importance of attracting entry into an auction.

II. The German Auction

In particular, I disagree with GRW's central claim that their model, as it stands, rationalises the behaviour of the two strongest bidders – T-Mobil and Mannesman, or "T" and "M", in GRW's terminology.[2] These bidders initially pushed up the price in the hope of driving out the sixth-strongest bidder, "bidder 6" in GRW's terminology, but then gave up pushing the price up so that the auction did actually end with six winners but at a much higher price than was necessary to end the auction with this number of winners. This seems bizarre. To put the point simply, consider T's and M's decision about whether to end the auction with six winners at some given price, or whether to push the price up further. Raising the per-block price by 1 euro costs T and M 2 euros each, since they would each win 2 blocks in a six-winner outcome. Their gain is the probability that bidder 6 quits, times their benefit from bidder 6 quitting. If it is worthwhile for T and M to push the price up in one round, but to stop pushing the price up in the next round, then the perceived probability of bidder 6 quitting in the next round must be both low, and also lower than it was in the last round. However, most observers thought the probability of bidder 6 quitting in the next round, conditional on not having previously quit, was high and increasing around the time T and M ended the auction (when per capita price levels were approaching those achieved in the UK) and was much lower earlier (a six-player conclusion for the auction became possible at 55% of the UK price levels). So any rationalisation of T and M's behaviour must explain this apparently irrational behaviour of theirs. But GRW's model sidesteps this basic issue, as I now explain:

[2] T-Mobil and Mannesman were subsidiaries of Deutsche Telekom and Vodafone, respectively.

III. GRW's Analysis of the German Auction

(This section can be omitted by readers who do not want too much detail.)

To understand GRW's argument – and why I believe it is incomplete in this context – consider the preferences of either one of the two strong bidders, M and T. At any point of time, it would like to end the auction only if it prefers this to waiting until the price has risen a small further amount, $\Delta\, price$, before the auction ends.

The gain from waiting is the probability, r_6, that bidder 6 will quit in the price interval, $\Delta\, price$, times the value of driving bidder 6 out. This value is itself the benefit, b, of winning a third block, including the benefits from excluding bidder 6 from the industry (leading to a more concentrated, and hence more profitable, market), less the current price of buying an additional block. That is, the total gain from waiting equals $r_6[b - price]$.

The cost of waiting is the extra price, $\Delta\, price$, paid on the two units that the bidder will win anyway, i.e., 2($\Delta\, price$). That is, the bidder would prefer to plan to end the auction if a further price rise of $\Delta\, price$ fails to drive out bidder 6, rather than end it now if

(1) $$r_6[b - price] > 2[\Delta price]$$

The bidder would prefer to end the auction now if

(2) $$r_6[b - price] < 2[\Delta price].$$

In GRW's model, bidder 6's value can only take one of two possible values, v_6' (strong type) and v_6 (weak type), and the auction cannot be ended before price $p\,(< v_6)$, so the only conceivably sensible strategies for the strong bidders are

a) to end the auction as soon as possible at p, or

b) to push the price up a further $\Delta price = v_6 - p$ to v_6 to drive out the weaker type of bidder 6, but then to end the auction, or

c) to push the price up further still, by an additional $\Delta price = v_6' - v_6$ more to v_6', to drive out both types of bidder 6.

The observed behaviour in the actual auction corresponded to case b) of GRW's model.

The condition for b) to be preferred to a) is the appropriate version of (1) or equivalently is GRW's equation (9).[3] The condition for b) to be preferred to c) is

[3] In GRW's notation, $b = v_{13} + b$ for the case of successfully driving out bidder 6 at price v_6.

the appropriate version of (2), or equivalently GRW's equation (6).[4] So these are the key conditions in GRW's Theorem.[5] If (6) holds there is an equilibrium in which outcome b) arises. (If (6) fails, both strong bidders prefer c), and either can unilaterally implement it.) If (9) holds, the equilibrium is unique. If (9) fails, outcome b) can still be an equilibrium of the model if (6) holds, since neither strong bidder can unilaterally end the auction, but the equilibrium is neither unique, nor plausible.[6] So for the observed play to correspond to a plausible equilibrium of GRW's model, both (9) and (6) are required.[7]

Noting that (9) and (6) are just my equations (1) and (2) suggests why GRW's theory seems unlikely to describe reality. Of course, (9) and (6) correspond to (1) and (2) evaluated at different values of r_6, b , *price* and Δ *price*, reflecting the different stages of the game at which (9) and (6) are computed. So the observed play can correspond to an equilibrium of GRW's model. But this requires that $[r_6 / (\Delta price)]$ not be too much lower when the strong bidders could first have ended the auction (when (1) must be satisfied) than at the actual end of the auction (when (2) must be satisfied).[8]

Furthermore, the tension between conditions (9) and (6) is more severe when the game is generalised to many small stages since the values of $[r_6 / (\Delta price)]$, b , and *price* to be substituted into (1) and (2) cannot then vary much between stages, and related conditions must then hold at all the stages – an issue that GRW do not address.[9] In particular, (1) must hold just before the auction ends,

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[4] In GRW's notation, $b = v'_{13} + b$ for the case of driving out bidder 6 at price v'_6 , but $r_6 = 1$ in GRW's model at stage c).

[5] GRW rename (6) as $"\Delta^{c}_{pr} \leq 0"$ in their statement of Theorem 1.

[6] This equilibrium is not plausible if (9) fails because in this equilibrium both strong players prefer outcome a) to outcome b), but both follow the strategy corresponding to b) because each expects the other to do this. This logic can only hold in the two-stage model: with more stages, each strong player would know that if it followed the strategy corresponding to a), then the other strong player would follow just one round of the auction later (if (9) fails) – that is, the players could trivially coordinate on strategy a) in the actual multi-round auction, which eliminates this equilibrium. This equilibrium is, of course, also Pareto dominated by the more natural equilibrium for the players in GRW's two-stage model, and GRW also eliminate this equilibrium in their limited extension to multiple rounds (see note 9). However, an equilibrium of this kind becomes more plausible if M and T are each uncertain that its rival shares its assessment of the parameters, or are uncertain about the rival's objectives – see section V.

[7] GRW note that Theorem 1 requires other conditions too.

[8] It does not seem likely that $(b - price)$ ever became very small because b includes both the value of a third block to a strong bidder and the value, *b* in GRW's terminology, of excluding bidder 6 from the industry, leading to a more concentrated and hence more profitable market. Therefore, b must be greater than $p_2 + b$, where p_2 is the expected maximum of the value of a fourth block to a strong bidder and a third block to a less strong bidder. And, as GRW point out, p_2 must itself be quite high for the GRW equilibrium to make sense – the logic of GRW's equilibrium requires p_2 to at least equal the final German auction price. (The very limited anecdotal evidence suggests that p_2 might have been, very roughly, in the region of the final German auction price.)

[9] GRW do briefly consider extending their model to many rounds of bidding, but when they do this they maintain the extreme assumption that bidder 6's valuation can take only

and (2) must hold at the price at which the auction ends. So if, as was the case in the actual auction, the price is changing only slowly between rounds, it is required that $\left[r_6/(\Delta price)\right]$ is falling (or at least not much increasing) at the end of the auction.

So, summarising the two previous paragraphs, GRW's equilibrium requires that, at the end of the auction, the probability of bidder 6 quitting conditional on not yet having done so is *both* not much increasing, *and* not much larger than at the lower prices at which the strong bidders could earlier, if they had both wished, have ended the auction.

And these two conditions seem implausible. A six-player conclusion to the auction became possible when Debitel quit at prices that were just 55% of the final UK prices (per capita).[10] The German auction actually finished at 94% of the final UK prices. The weakest of the six remaining bidders was generally thought to be either Mobilcom or "Group 3G", the joint-venture between Telefonica and Sonera, so r_6 represents the probability that one of these would quit in the next round, conditional on their not yet having quit. But Telefonica and Mobilcom had quit the UK auction when the price levels had reached 94% and 100% of the final UK price level, respectively.[11] Mobilcom (at least) had made public statements that suggested that it was likely it would bid as far as it had in the UK[12], and outside observers also thought that these bidders would probably go a lot further than 55% of the UK auction price, but might quit at around the final UK price levels. Certainly, most plausible distribution of valuations implied that at the end of the auction the probability of bidder 6 quitting was both much higher than earlier, and increasing, and either of these implications is sufficient to rule out GRW's equilibrium.[13]

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two possible values, v_6 and v_6. Thus in their extension there is no possibility of bidder 6 quitting before v_6, or between v_6 and v_6, so the additional rounds of bidding are mostly irrelevant and (1) and (2) are relevant only at the same points at which they matter in the two-stage game, i.e., GRW's conditions (9) and (6) suffice as before. In a proper many-round extension of GRW's game in which it is also recognised that bidder 6's valuation is not restricted to just two possible values, conditions related to (1) or (2) must hold at each round of the game. (One difference that arises even in GRW's simplified many-round version is that (9) and (6) are both required for GRW's result to be an equilibrium.)

[10] Ending the auction at these prices would have required the cooperation of all six bidders, but this could probably have been obtained. And even if this seemed hard, M and T could together have ended the auction once the other four bidders had stopped bidding for three blocks; none of the other bidders had high bids for three blocks beyond round 136 when the prices were 70% of the final UK price, and all could be proved to have lost eligibility for three blocks shortly thereafter.

[11] Mobilcom was in large part owned by France Telecom which was also part owner of NTL Mobile, the last bidder to quit the UK auction.

[12] It may be objected that such statements were cheap talk. But following through on them may be necessary to maintain management credibility, they probably reflected an availability of finance, and – what matters – they seemed credible to observers at the time.

[13] Although GRW argue (in the last paragraph of their Section V) that it was reasonable to expect that bidder 6 might quit at some point before the final German auction price, they fail to consider the crucial questions about the *relative* likelihoods of bidder 6 quitting at a very low price, or at close to the final UK prices.

In brief, GRW's equilibrium requires, roughly, that the strong bidders thought it relatively likely that Mobilcom or Group 3G would quit while prices were well below UK levels but then, having seen that Mobilcom and Group 3G did not quit at such low prices, the strong bidders thought it both relatively unlikely, and increasingly unlikely, that they would quit while prices were close to UK levels. And this seems unreasonable.

IV. What Actually Happened in the German Auction?

Whilst no-one can be certain, it seems that other factors are required to explain the behaviour of T-Mobil and Mannesman in the German auction. Some of these factors are discussed in Klemperer (2002a, b).[14]

They include the complexity of the rules and the opacity of the information available to bidders about others' bids, which made it hard for bidders to figure out optimal strategies (T may simply have made a mistake in failing to heed M's signal suggesting that they both reduce demand early on) or to understand their rivals' thinking. Klemperer (2002b) stresses the apparent lack of trust and understanding between the two strong bidders, and discusses why this mistrust might have arisen.

Furthermore, the strong bidders may not simply have been maximising expected profits. M and T may have focused more on their performances *relative* to each other, as might be rational behaviour for managers who had private career concerns, or were concerned that their firm seemed well-managed and deserving of further investment, etc. Relative-performance concerns may explain the auction's outcome, especially in conjunction with the mistrust between the bidders, as we explain in more detail in the next section.

Other contributory factors to T's behaviour that have been suggested include that T felt pressured by the stockmarket's response to the rising auction prices (and that T had not fully anticipated this), and even that T's objectives were affected by the fact that it was majority owned by the German government.

V. A Relative-performance-maximising Theory of the German Auction

GRW explain that if, for example, M reduced demand to 2 blocks while T did not, and T then won 3 blocks by driving out bidder 6, there would then have been a second auction for the remaining block which would most probably have

[14] *Ewerhart* and *Moldovanu* (2001) make interesting points about the German design but in a model in which there is only a single strong bidder, so they cannot address why initially both strong bidders pushed up the price, and then both stopped doing so. Also they do not model the second auction that would have taken place if just one strong bidder had pushed up price and subsequently driven a weak bidder out, and this possible second auction may have played an important role in behaviour in the main auction, as we discuss in section V.

been won by M at an expected price p_2 (in GRW's terminology) so both M and T would have ended with 3 blocks but having paid different prices for them.

Recall also from our discussion above that when prices are still low (e.g., around 55% of the final UK auction price) the probability of bidder 6 quitting is low, so it probably maximises both firms' expected profits to reduce demand to 2 blocks and end the auction at low prices. However, if one firm, say M, reduces demand while T fails to do so and continues to push the price up, there is some – perhaps small – probability that bidder 6 will be driven out at a price $\tilde{p} < p_2$, in which case T and M will both end up with 3 blocks (assuming that M wins the block in the second auction), but T will on average pay less for its blocks than M (since T pays $3\tilde{p}$, but M expects to pay $2\tilde{p} + p_2$). Even in this case T and M may both be worse off in absolute terms than if T and M had both reduced demand to win 2 blocks at low prices. And because the chance of driving out bidder 6 at a low price is not that high, the more probable result would simply be that T would eventually reduce its own demand to 2 blocks later on, in which case both T and M would be much worse off than if they had both reduced demand earlier. But note that T always improves its performance relative to M by failing to reduce demand at prices below p_2.

Furthermore, even if each firm is actually an ordinary profit maximiser, but each firm expects the other is likely to maximise relative performance, then neither firm will reduce demand first (since being the only firm to reduce demand when prices are low risks paying $2\tilde{p} + p_2$ rather than $3\tilde{p}$).[15]

Similarly, when prices are higher (e.g., close to the final UK levels), it may maximise both M's and T's expected profits to push up the price to drive out bidder 6. But if one of the firms, say T, reduces demand to 2 blocks and lets M push up the price on its own to drive out bidder 6 at a price $p^* > p_2$, then again T and M will both end up with 3 blocks (assuming that T wins the block in the second auction) but T will pay less on average for its blocks than M pays (since T expects to pay $2p^* + p_2$, but M pays $3p^*$. So T would improve both its relative and its absolute performance if it could reduce demand alone, and M would then improve its relative performance by reducing demand along with T, even though M might increase its (and T's) absolute profits by continuing to raise price to drive out bidder 6.

The story told thus far is extreme. True, there is anecdotal evidence that firms' managers cared about relative performance, and concerns about relative performance also seem to have played at least some role in other European 3G auctions (see, for example, Klemperer 2002c). But M and T were surely not concerned only with relative performance. So one might have expected M and T to attempt to co-ordinate their behaviour to reduce their demands at low prices to maximise both of their absolute profits. Indeed it seems that M did initially try to signal to T that they should do just this (see GRW and Klemperer 2002a,b).

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[15] A similar argument is that if all firms are known to be ordinary profit maximisers, but firms are unsure that their rival has the same estimates of parameters such as r_6, then firms may be unwilling to reduce demand first.

But T could not know whether M was sincere, and the firms apparently mistrusted each other's intentions (see Klemperer 2002b) and, as we have seen, there are very strong relative-performance arguments (it suffices that each feared that the other might maximise relative-performance) why neither was prepared to be the first to reduce demand while prices were still low.

T then reduced demand later when prices were higher, perhaps for relative-performance reasons[16] ,and/or because this could also improve its absolute performance if M failed (or was unable) to follow its demand reduction.[17,18] And once T had reduced demand, there are several possible reasons why M followed straightaway. First, M had a strong relative-performance incentive to follow immediately, as explained above. Second, M may have wanted to develop a reputation for co-operative behaviour in which M and T parallel each other's behaviour – a kind of “relative-performance” effect but strictly driven by M’s long-run absolute-performance goals (see Klemperer 2002b). Third, M might have been concerned only with its (short-run) absolute performance, but it might all along have taken the view that this would be maximised by M and T both reducing demand, and it might have stuck to this view (i.e., M may have been extremely pessimistic about driving out bidder 6 at low prices and, even though driving out bidder 6 seemed more likely at high prices, remained fairly pessimistic – see Klemperer 2002a); this is consistent with M’s early behaviour (signalling T to reduce demand but not unilaterally reducing demand) if it feared that T might place a large weight on relative performance.

Of course, there may be other reasons for the observed behaviour in the auction. For example, fear that one's rival has very different perceptions from one’s own about the chance of driving out bidder 6 can have similar effects to fear that

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[16] It might seem that a firm could protect its relative performance by following a strategy of quitting only if its rival quits when prices are above p_2. However, it takes time to be sure the rival has quit (because the auctioneer gave the bidders only limited information about their rivals’ bidding), and it also takes time to respond. Furthermore, some of the weaker players may have been staying in the auction in the hope of being a winner in a five-firm industry, which would have been the outcome if M and T had successfully driven one of them out – in particular, each of Mobilcom and Group 3G might have hoped that the other (or possibly E-plus or Viag) was the “bidder 6” who might have been driven out. In this case, when one of M and T quits bidding for a third block, these weaker players may expect the other of M and T to try to follow suit and may therefore try to quit first rather than find themselves stuck as winners in a much-less-profitable six-firm industry. So if either M or T failed to quit first when prices became high, it might have risked being stranded buying a third block at a higher price than its opponent, and achieving a very poor relative-performance.

[17] If T thought M was not too concerned with relative performance, T could improve both its relative and absolute performance by reducing demand once the price exceeded p_2, and free-riding on M continuing to push price up to drive out bidder 6. And even if M was concerned with relative performance, there was the possibility that M would have been unable to follow T (see note 16).

[18] Of course, there may be other reasons, such as T being influenced by stockmarket pressure or its government ownership (see section IV).It might be argued that another possibility was that b was not in fact that high. However, this seems less likely since b must have substantially exceeded p_2 (see note 8) and if p_2 were low then both firms would have been willing to reduce demand early on for relative-, as well as absolute-, performance reasons.

one's rival is a relative-performance maximiser[19], and Klemperer (2002b) emphasises the mistrust and misunderstanding between the bidders. But the point is that the apparently puzzling behaviour can be explained by postulating only a limited concern with relative performance. To explain why M and T failed to reduce demand early on, it suffices that each firm thought its rival put some weight on relative performance; it is not necessary that either firm actually did so, and even the conjectured weights on relative performance need not have been large if firms were also uncertain about their rivals' perceptions about bidder 6's behavior, etc. And not much more concern with relative performance is needed to explain the firms' later behaviour in the auction.

VI. The Austrian and Swiss Auctions

Turning to other 3G auctions, I disagree with GRW's assertion that the Austrian auction design was superior to the Swiss, except to the extent that the Austrian reserve price was somewhat more realistically chosen than the Swiss reserve. Neither auction attracted more bidders than there were winners, and neither involved any significant bidding. (Although there was a semblance of serious bidding in the Austrian auction, the bidders there were put under considerable pressure from the authorities to continue the bidding, and it was widely believed that the bidding only lasted the few rounds it did in order to create some public perception of genuine competition and reduce the risk of the government changing the rules.) Neither auction achieved more than 11% more than the reserve price that had been set. The only important difference is that the Swiss reserve price had been set ludicrously low at 20 euros per capita, while the Austrian reserve price, although still far lower than it should have been, was 90 euros per capita.[20] But revenues in excess of 300 euros per capita should probably have been attainable in both auctions, see Klemperer (2002a). So both of these auctions were failures, and both were intensely embarrassing to their respective governments. Indeed there was no successful European 3G auction after the UK and German auctions until the Danes switched to a sealed-bid design. I have discussed all these auctions in more detail in Klemperer (2002a).

VII. The Importance of Entry, and the UK Auction

Where I do agree very strongly with GRW is on the importance of attracting entry into an auction.[21] As GRW say, "competition is not a free good" and auctions must be designed with this in mind. However, this does not imply that there is any single best design. Often a sealed-bid design is best for attracting entry, as is suggested by the Danish example in the previous paragraph. But this need

[19] In particular, either fear can make a bidder unwilling to reduce demand first when prices are low, because of the perceived risk that the rival will not follow. See note 15.

[20] Of course, Switzerland sold 4 licences while Austria sold 6, but the Swiss could obviously have used their same design to sell 6 licences if they had preferred that outcome.

[21] I emphasised this in *Bulow* and *Klemperer* (1996), and *Klemperer* (1998, 2000, 2002d).

not be the case. The UK design was appropriate in its context, because the UK auction was the first 3G auction and was therefore unlikely to suffer from entry problems. (See Klemperer (2002a,b) for more discussion of why being first was so important.) Indeed the UK auction attracted 13 bidders compared with the 7 that entered the German auction. It seems improbable that the German design would have usefully increased competition in the British auction, and the British design had other advantages over the German design[22], see Binmore and Klemperer (2002) and Klemperer (2002a) (though my view may be coloured by my having been the principal auction theorist for the UK auction[23]). In another context, when Peter Cramton, Eric Maskin and I advised on the UK's 2002 auction for greenhouse gas emission reductions, we chose a uniform-price ascending design as being most likely to attract "small" bidders who did not have the resources to work out how to bid correctly in a discriminatory price auction.[24] And nor, of course, is entry always the key issue. As I discuss further in Klemperer (2002d), good auction design is not "one size fits all", but must always be tailored to its context.

Summary

Grimm, Riedel and Wolfstetter (2002) have developed an intriguing explanation for the apparently puzzling bidding in the year 2000 German 3G telecom auction. These comments on their paper discuss why I do not find their explanation fully satisfactory, and suggest alternative explanations, including a relative-performance-maximising theory. I also comment briefly on issues about several other 3G auctions.

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[22] One advantage is identified in note 16: in the German design a bidder might rationally follow a strategy that could mean that it felt sorry to have won as soon as the auction finished.

[23] I was the principal auction theorist advising the Radiocommunications Agency which designed and ran the UK auction. *Ken Binmore* had a leading role and supervised experiments testing the proposed designs. Other academic advisors included *Tilman Börgers*, *Jeremy Bulow*, *Philippe Jehiel* and *Joe Swierzbinski*.

[24] *Larry Ausubel* and *Jeremy Bulow* were also involved in the implementation of this auction. Strictly this was a descending auction, since the auctioneer was buying reductions in emissions rather than selling permits to emit, but the auction corresponded to an ascending auction to sell emissions.

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