Auctions

SUMMARY

The recent spectrum auctions in Europe have shown that serious problems can arise in auctions where multiple complementary objects are being sold (such as blocks of radio spectrum) that will subsequently be used by the winning bidders to compete against each other in downstream markets. Other important instances of such situations include take-off and landing slots at airports and rights for electricity and gas transmission. We first review some of the theory describing multi-object auctions. We next outline the importance of strategic effects arising in auctions that are followed by competition between the bidders, and the tension arising between various goals such as efficiency and revenue maximization. Although more flexible auction formats can have virtues (particularly in taking into account complementarities), they can also be manipulated by bidders to build market power to the detriment of consumers. We next apply these insights to the recent European UMTS licence auctions. Finally we draw the main conclusions and policy implications.

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An economic perspective on auctions

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1. INTRODUCTION

This paper is about what happens in auctions when either the objects for sale, or the bidders for those objects, are interdependent. Recent events, particularly but not only in the auctions for spectrum for third generation mobile telephony, have shown us that when the assets for sale are characterized by important complementarities, or when they are inputs that will subsequently be used by the successful bidders in imperfect competition with each other (so that allocations to one bidder create externalities for others), auctions can behave in surprisingly problematic ways. Although auctions have been continuously used since antiquity, and have a wide range of modern applications (including to the sale of treasury bills, procurement contracts, consumer to consumer, business to consumer and business to business Internet transactions, real-estate, electricity and gas contracts and bankruptcy proceedings), it is only in the last few years that we have begun to appreciate the problems posed by complementarities and strategic externalities. This paper presents the relevant theory,

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shows why it matters, and uses it to understand the recent spectrum auctions in Europe, where both of these features were present.

Most of auction theory describes simple settings in which bidders are interested in one object only, and bidders care only about whether or not they get this object and at what price. In such settings, familiar auction procedures are known to have desirable properties, notably the two properties of allocating objects efficiently to bidders, and of maximizing revenue to the seller. For example, if bidders know the value of the good to themselves, an ascending price auction allocates the object efficiently to the bidder who values it most. When there are no asymmetries between the bidders, standard auctions augmented by suitable choices of reserve prices (or entry fees) also allow the designer to extract the maximal possible revenue. For these simple settings, therefore, there is no conflict between maximizing revenue and allocating the objects efficiently – well-designed auctions can do both.

The theory that describes these cases may break down when there are several objects for sale and bidders are potentially interested in more than one object – we refer to such situations as multi-object auctions. The problem here is that the values of the multiple objects to the bidders may be interdependent. Consider an auction of licences to operate radio stations in two or more large regions. A national licence, covering both regions, might be worth much more to the parties than licences for a single region. These issues played a major role in the design of a planned auction for radio licences in Holland.[1]

The theory also breaks down when the bidders care not just about whether they themselves acquire the objects for sale, but also about who else does. The most obvious reason why they might do so is that the other bidders are their competitors in a market in which the objects for sale will be used as inputs. Consider an auction for radio spectrum for use in mobile telephony. After the auction, firms compete in the market: their profits will be affected by the market structure that was determined at the auction. This, in turn, implies that at the auction stage bidders need to work out which other bidders will get licenced (and with what rights). Their bidding strategy depends on the answer. More generally, whenever bidders expect to interact after the auction, they will care about the entire allocation of objects to all bidders and not just to themselves.

Both multi-object auctions and auctions with externalities lead to subtle kinds of strategic behaviour that are not present in more standard contexts. One result is that severe conflicts can appear between various possible goals of the auction process, and particularly between the goal of revenue maximization and the goal of efficient allocation. This means that an informed auction design requires a careful identification of the auction's goals and features, in particular which interdependencies between

[1] This auction was designed by a group including one of the authors.

objects or between bidders, that will influence bidders' behaviour. First and foremost, these features relate to the nature of demand for the objects for sale, or the nature of supply when procurement contracts are at stake.[2]

Our main purpose is to reassess the performance of multi-object auctions with externalities, and, in particular, to investigate to what extent greater flexibility makes auctions more efficient. What do we mean by greater flexibility? In a multi-object auction, flexibility means that bidders are allowed to bid for combinations of objects rather than being restricted to independent individual bids for whatever definition of objects the auctioneer has decided to put up for sale. In an auction where market structure matters, flexibility means that the market structure should be determined by the outcome of the auction rather than imposed at the outset by the designer.

Many people think that flexibility is a desirable characteristic of well-designed auctions. And there are indeed good reasons for thinking so – in particular, flexibility allows complementarities between the objects of sale to be taken into account. But we argue here that this conclusion is valid only when there are no important externalities between bidders. When market structure considerations matter, there is a risk that some firms will use the flexibility of the auction as an instrument to increase or cement market power, to the detriment of consumers. To the extent that policy-makers care about consumers' welfare, flexibility may need to be limited in order to ensure that consumers do not lose out.

The contribution of this paper, then, is not just to point out the significance of complementarities and market structure for the conduct of multi-object auctions – both of these points have been made before. Most importantly, it is to show that the two problems are linked; in particular, solutions to the problems of multi-object auctions that work well in the absence of externalities may not work when market structure matters. Conversely, simple solutions to problems of market structure (such as restricting the number of objects any one bidder can acquire) may be inefficient if complementarities are important. The two problems need to be viewed together.

In the last part of the paper we look more closely at the recent European UMTS auctions. But we want to stress that the features discussed here are common to a large number of allocation decisions arising from the recent wave of deregulation in various industries. We illustrate below with two examples:

(1) **The allocation of airport take-off and landing slots.** The EU is currently looking for workable allocation procedures, including various auction formats, in order to assign slots at Europe's most congested airports (a related issue is the

[2] Even the 'mere' decision about what objects to auction can have far reaching consequences. While the Mona Lisa is a Mona Lisa, in some of today's complex markets the physical definition of the traded objects is not always clear. The precise structure of the traded goods and bids plays a main role in determining whether the auction procedure can accurately represent the agents' preferences. This is not an abstract point but one with major policy implications. For instance, a central point of dispute in a recent case involving the allocation of broadcasting rights for football matches in France concerned whether the division of matches into lots for sale had been designed to influence the result in an anti-competitive way.

allocation of terminal gates).[3] Scarcity of slots has become a major problem following deregulation and the emergence of numerous airlines besides the former national flag carriers. The current system is based on the so called 'grandfathering rule': the resources are shared among historical users according to past utilization, and explicit trading of slots is not allowed. For example, British Airways controls 38% of the slots at Heathrow, while Air France, Lufthansa and KLM all control much larger shares at their main hub airports (*Financial Times*, 16/3/2001). Interdependencies between both the objects for sale and the bidders for those objects are very important here. First, there are obvious chronological complementarities between landing and take-off slots at the same airport, and both chronological and geographical complementarities between slots at different airports. Secondly, control over slots seems to be an important strategic asset governing both competition among existing airlines and the entry of new firms in the market. Thus, bids at an auction for slots will often reflect market power consideration besides pure economic value. Under the current 'use it or lose it' rule, incumbents have incentives to persist with inefficient schedules and inappropriate plane size in order to pre-empt new entrants (the practice has earned the name 'predatory scheduling'). It is interesting to note that the approval of several major alliances or mergers has been made contingent on relinquishing slots at hubs.[4]

(2) **The allocation of entry and transmission rights in networks.** The deregulation of formerly monopolized industries such as gas and electricity is often accompanied by the creation of auction-like market places where firms compete for the right to 'inject' their commodity in an (often constrained) network administered by an independent system operator. Besides the complexity of trading goods whose transmission is governed by idiosyncratic physical or chemical properties, a continual challenge is to ensure that the relatively few competing firms do not use their market power to the detriment of final consumers. As an example, consider the UK auctions of entry rights to the national gas transmission system, started in 1999. McDaniel and Neuhoff (2002) list several main properties of these auctions: multiple units of access rights are concurrently offered at each one of the existing beach terminals; the value attributed by a shipper to the rights at one terminal depends on the price paid at other terminals; the number of rights issued for a terminal depends on the quantity required at other terminals because most capacity constraints are not at terminals but in the network itself; the auctioneer is not interested in maximizing revenue, but instead cares about efficiency and safety in production and supply. The auctions conducted so far have been for the spot market. There are recent plans to add

[3] The problem is not confined to the EU: all major airport operators struggle to find solutions. A particularly acute problem occurs at La Guardia, NY: between 10% and 25% of delays across the US have been traced to problems there. A newly introduced lottery system was not able to ease congestion, and the Port Authority of New York and New Jersey plans now to auction off slots (see *New York Times*, 6/6/2001).

[4] British Airways agreed to relinquish 168 slots per week in order to facilitate the approval of its alliance with American Airlines. In clearing the Lufthansa-Eurowings merger, the German Cartel Office ordered Lufthansa to provide upon request up to three take-off and landing slots that can be used in 'an economically viable way' at Frankfurt, Munich and Dusseldorf airports.

auctions for long-term (7 year-) access rights in order to provide signals needed for long-term investment in transmission capacity. McDaniel and Neuhoff note that the division of transmission rights between spot and long-term auctions will have an impact on efficiency since incumbents have an incentive to foreclose entrants by requesting excessively large quantities of access rights in the long-term auctions.

The rest of the paper is organized as follows. We first briefly review some central theoretical insights about multi-object auctions. We then move to a discussion of auctions with interaction among bidders. We then apply these insights to a major case study, the 2000–2001 European UMTS licence auctions. We conclude with several policy recommendations.

2. MULTI-OBJECT AUCTIONS

We first review the theoretical results available for multi-object auctions. The insights of simple auction theory can apply to some kinds of multi-object auction, so the purpose of this section is to show just what are the aspects of multiple-object auctions that cause problems. The first three results indicate circumstances under which intuitive extensions of simple auctions can still be used efficiently, while the fourth indicates a more sophisticated procedure that can be used in a wider class of settings:

(1) If bidders demand just one unit and if the objects are homogeneous, efficiency can be achieved by a simple extension of the second-price sealed-bid auction, called the $(k+1)th$ price auction (where k is the number of units for sale). Here the bidders submit simultaneous bids for one unit each. The bidders with the k highest bids win a unit each, and they each pay the same price, equal to the $k+1th$ bid.

(2) If bidders have unit demand but the objects are heterogeneous, a simultaneous ascending-price auction is efficient.[5] In such an auction, prices start initially at a low level, and bidders express demand by placing a bid on one of the objects. The prices of those objects that receive more than one bid are raised, and the procedure is repeated until demand is equal to supply for each object.

(3) If bidders demand more than one unit, but there are no complementarities nor substitutability (i.e., if valuations for bundles equal the sum of the valuations for the individual objects in the bundle), efficiency can be achieved by organizing separate one-object ascending auctions.

(4) In so-called private value settings (where bidders know the value they attach to goods and do not need to learn by observing the bids of others), efficiency can be achieved by a famous mechanism due to Vickrey, Clarke and Groves (VCG), provided bidders are risk neutral and do not face binding budget constraints. This mechanism requires that the agents express in their bids the values attached to every possible

[5] There are some important behavioural caveats. See Demange *et al.* (1986), and Milgrom (2000). Gul and Stacchetti (2000) and Ausubel and Milgrom (2001) describe the difficulties with multi-unit demand.

> allocation of objects among all bidders. The pricing scheme is complex: each bidder pays an amount that corresponds to the shadow cost of his bundle of objects – calculated as the value which would be foregone by not allocating his acquired bundle to the next most efficient use. Given such 'prices', bidders completely internalize the social value of their decisions, and an efficient outcome results.

The main problem with the VCG mechanisms is that, except in very special cases, they do not translate into simple, intuitive auction formats. Complexity is generally perceived as a major drawback by practitioners.[6]

It should be mentioned that, in general, in multi-object auctions with heterogeneous objects and common rather than private values[7] no mechanism whatsoever can allocate the goods efficiently if either complementarities, substitutability or allocative externalities are present (see Jehiel and Moldovanu, 2001a). In other words, we know there exists no general equivalent of the VCG mechanism in the multi-object, common value case. Moreover, the second-best mechanism has not yet been identified.[8]

So how exactly does the multiplicity of objects cause problems? We next illustrate several important strategic effects induced by the presence of multiple objects. The first is known as *demand reduction* and is similar to market power effects in monopsony. The second is due to complementarities and is known as the *exposure problem*; bidders will be afraid to bid for component items of a valuable bundle if they are not sure whether they will be able to acquire the other components. Allowing bidders to make combinatorial bids (bids for whole bundles) as well as individual bids can help to alleviate the exposure problem. On the other hand, allowing combinatorial bids while at the same time forbidding individual bids may lead to an increase in revenue at the expense of efficiency: the revenue-maximizing combinatorial bids bundle together components that would be better allocated to different bidders. This effect is also known from the study of monopoly power where it is called *bundling*. Finally, a fourth effect is that bidding for multiple objects may facilitate *tacit collusion* between bidders by allowing them a natural means to share the auctioned objects. None of these problems is necessarily insoluble – but it is important to understand what the strategic effects are in order to devise effective policy responses.

2.1. Multi-unit demand and demand reduction

When bidders demand more than one of the objects for sale, distortions can occur that are similar to those in ordinary markets with monopsonistic buyers: bidders can

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[6] See Ausubel and Milgrom (2001) for more drawbacks of VCG mechanisms. Ausubel (1997) offers an ascending auction format that coincides with the VCG pricing scheme if there are no allocative externalities and no complementarities.

[7] These are situations where the valuation of one bidder depends on information available to another. Think, for example, about an auction of oil-fields where some bidders have conducted geological surveys.

[8] This should be contrasted to the case where one object is auctioned, but bidders care about several properties of this object. In that case full-efficiency is not possible (Dasgupta and Maskin, 2000; Jehiel and Moldovanu, 2001a) but the second-best mechanism is readily available.

distort their expressed willingness to pay for the marginal unit in order to influence the price of the remaining units. We described above the mechanism that can allocate multiple units efficiently when buyers demand only one unit each: it is the $k + 1th -$ price auction. The natural generalization of this to the case when bidders demand several units is the uniform-price auction. Here bidders submit demand *functions* (i.e., bids for 1 up to k units), and the units are allocated to maximize the values expressed by these functions; every allocated unit is sold at the same price p, the minimum price where aggregate demand coincides with supply.

Unfortunately, this uniform price auction can be inefficient since bidders have an incentive to lower their demand on all units but the first one they acquire.[9] In doing so, they affect downwards the selling price and pay a lower price on the remaining units.[10] Box 1 illustrates with a simple example.

Box 1. Demand reduction in a wine auction

Three identical cases of Bordeaux wine are sold through a uniform price auction. There are three potential bidders, $i = 1,2,3$. Bidders 2 and 3 are interested in one case only; their valuations are 1 and 0.25, respectively. Bidder 1 is potentially interested in all three cases. His valuation is 10 for the first unit, 5 for the second, and 2 for the third.

Efficiency dictates that bidder 1 gets all three cases. Bidders 2 and 3 bid their true values for one case whatever bidder 1 does. If bidder 1 expresses his true demand, the minimum price where demand equals supply is (slightly above) 1, and bidder 1's payoff is given by $10 + 5 + 2 - 3 = 14$. However, in the equilibrium of the uniform price auction, bidder 1 will decrease his demand to only two cases (e.g., he will bid 15 for either two or three units). This lowers the selling price per unit to 0.25, yielding for bidder 1 a higher payoff of $10 + 5 - 0.5 = 14.5$. The allocation is inefficient since bidder 2 obtains one case.

It is important to note that it is not just the uniform price which is causing inefficiency here. In any 'pay your bid' type of auction (such as the discriminatory auction, which has the same allocation rule as the uniform auction, but each bidder pays his own bid on the units he obtains) agents have incentives to bid less than their values even on the first unit. So a discriminatory auction may also be inefficient.

[9] The uniform-price auction has been hailed by famous economists (including Nobel prize winners) as the most suitable method for auctioning Treasury bonds. The argument was that the uniform-price auction carries over to the case of multiple units the desirable characteristics of the second-price auction. The argument is incorrect since unit-demand is hardly realistic for Treasury bonds.

[10] See Noussair (1995), Ausubel and Cramton (1998) and Engelbrecht-Wiggans and Kahn (1998). Demand reduction effects are less severe if there are many bidders.

2.2. Complementarities and exposure

Complementarities occur when the value attached to a bundle of objects is higher than the sum of the values attached to the individual objects in the bundle (for instance when there are 'synergies' among the objects). In principle the best way to deal with this problem is to allow for 'combinatorial' auctions where agents can place bids directly on entire bundles (Ausubel and Milgrom, 2001 describe an ascending version of such an auction, generalizing earlier *deferred-acceptance* algorithms from matching theory). Forbidding such bids may give rise to the so-called *exposure problem*: bidders are afraid to get stuck with an expensive but worthless part of a valuable bundle, and may therefore choose not to bid altogether (see Box 2).

Box 2. The exposure problem

There are two parking slots, and two bidders. Bidder 1 has a car and a trailer. He values the two parking slots together at $100, while attaching a value of zero to each individual slot. Bidder 2 has only a car and values any one slot, or the pair, at $75. Efficiency dictates that bidder 1 should get both slots. But if the auction format does not allow bids on the package of two slots, any positive bid on an individual slot exposes bidder 1 to the danger of obtaining only that slot alone – an alternative valued at zero. The only equilibrium in a simultaneous ascending auction without combinatorial bids is for the first bidder not to participate (since otherwise he needs to bid up to $75 per slot in order to outbid the other player). This example is taken from Cramton (1997).

So when there are multi-object auctions with complementarities, insufficient flexibility can lead to inefficiency. However, taking complementarities into account is not necessarily easy. Simple combinatorial auctions can give rise to a free-riding problem among bidders with 'small' demands (see Theorem 6 in Milgrom, 2000). But sophisticated combinatorial auctions – like Vickrey-Clarke-Groves mechanisms – are complex to conduct and to participate in. Even computing how to allocate objects, given the bids, constitutes a so-called 'NP-hard problem' for which no reasonable[11] algorithm is known. Overall, more research is needed to assess the pros and cons of combinatorial auctions (this includes relying on experimental work such as Plott, 1997).

[11] That is, an algorithm whose number of steps increases polynomially in the auction's parameters. See de Vries and Vohra (2000) for the computational aspects of combinatorial auctions.

2.3. The tension between efficiency and revenue

As we described above, when there is a single object for sale and there are no asymmetries between bidders, standard auctions can maximize revenue and allocate objects efficiently. There need be no conflict between these goals. This is no longer true in multi-object settings, even if the situation is symmetric and there are no complementarities.[12] The main feature in the example in Box 3 is that bidders do not rank the objects in the same order of values. Allowing combinatorial bids while at the same time forbidding bids on single objects raises the revenue from the auction but at the cost of inefficiently allocating all goods to a single bidder instead of allocating them to different bidders.

Box 3. Efficiency or revenue?

Consider an auction for two objects A and B, and two bidders, 1 and 2. Valuations for the bundle $\{A, B\}$ are equal to the sum of the valuations for the individual objects, and assume these to be as follows:

$$v_1^A = 10; \quad v_1^B = 7$$
$$v_2^A = 8; \quad v_2^B = 12$$

The value maximizing auction (which puts the objects in the hand of those who value them most) is simply given by two separate second-price auctions, one for each object: object A goes to bidder 1 for a price of 8, while object B goes to bidder 2 for a price of 7. Total revenue is 15. But, consider now a single second-price auction for the entire bundle $\{A, B\}$. Then the bundle will be acquired by bidder 2, for a price of 17! Hence, revenue is higher in the bundle auction, but object A is misallocated.

2.4. Tacit collusion

Illegal explicit collusion can be dealt with by using standard anti-trust regulatory measures. But the presence of multiple objects for sale creates new possibilities for 'tacit' (and often legal) collusion: firms coordinate their bids instead of competing. The main idea is to share the objects at low prices instead of trying to buy more of them while pushing prices up.[13] Ascending price formats are more vulnerable to tacit collusion since they offer repeated opportunities to signal intentions and make threats. Box 4 describes a clear recent case. In contrast, sealed bid auctions greatly

[12] The point has first been observed by Palfrey (1983). See also Jehiel and Moldovanu (2001a) for an explicit interpretation in terms of the conflict between efficiency and revenue, and a relation to the revenue equivalence theorem. That theorem implies that all efficient multi-object auctions yield the same revenue.

[13] Wilson (1979) offers an early analysis.

reduce opportunities for signalling, but run the risk of yielding an inefficient allocation (since private information does not get as properly aggregated (Milgrom and Weber, 1982) or gathered (Compte and Jehiel, 2000)).[14]

Box 4. The German GSM auction

In October 1999 Germany auctioned ten blocks of paired spectrum to the four GSM incumbents. Nine blocks were identical, each consisting of 2 × 1 MHz, while the tenth block consisted of 2 × 1.4 MHz. The auction was conducted in a simultaneous ascending format. After the first round, the highest bidder on all ten blocks was Mannesmann (one of the two large players), which offered DM 36.360.000 for each of blocks 1–5, DM 40.000.000 for each of blocks 6–9 (recall that these blocks were identical to blocks 1–5!), and DM 56.000.000 for the larger block 10. In the second round, T-Mobil (the other big player) bid DM 40.010.000 on blocks 1–5, and the auction closed! Note that minimum increments had to be 10% of the last high bid. Hence, each of the two larger firms got five blocks, at a price of DM 20.000.000 per MHz. Here is what one of T-Mobil's managers said: 'No, there were no agreements with Mannesmann. But Mannesmann's first bid was a clear offer. Given Game Theory, it was expected that they show what they want most' (*Frankfurter Allgemeine Zeitung*, 29/10/1999, p. 13).

3. AUCTIONS AND MARKET STRUCTURE

Auctions with allocative externalities cover situations in which bidders care about the entire allocation of goods.[15] This is particularly relevant if after the auction there is competitive interaction among the bidders, as in auctions for electricity, natural resources, government licences, landing slots, and even Treasury bonds (where one large player may try to 'corner' the secondary market). Thus we now have in mind situations with two stages: at the first stage some objects are allocated through auction; at the second stage bidders at the auction compete in a downstream market.

We begin by considering some of the ways in which these externalities complicate the use of auctions; in the next section, however, we go on to derive some reasonably robust conclusions for policy. But it is important to note that the very policy instruments that can most help in resolving problems due to multiple objects (such as combinatorial bids for taking complementarities into account) can then pose significant anticompetitive risks once there is scope for firms to manipulate market structure.

[14] Klemperer (2000) advocates the use of a mixed ascending-sealed-bid format.

[15] See Jehiel and Moldovanu (1996, 2000a), and Jehiel *et al.* (1996, 1999).

3.1. A two-way interaction

Whenever the auction's outcome influences the ensuing competitive interaction, bidders need to take this into account at the bidding stage. The auction's outcome influences the future interaction, while the future interaction influences the auction's outcome through the participants' expectations about their payoffs in various future scenarios.

Even in simple one-object settings the analysis of externalities can be quite subtle. One reason is that the notion of a bidder's 'valuation' of the object is ambiguous: it depends on his expectation about what will happen if he does not buy the object. If he expects the winner to be one of the 'tough' competitors, he will be ready to pay a high price; if he expects the winner to be one of the 'soft' competitors, his willingness to pay will be lower.

Several new phenomena arise in auctions with externalities:[16]

(1) There may be several equilibria with different allocations. This can make the outcome of the auction (including how efficiently it allocates objects) very uncertain, and dependent on other external factors.
(2) The objects may not be allocated to the efficient buyers even when there is only one equilibrium.
(3) Bidders may have incentives not to participate in the auction since their mere decision to participate influences the willingness to pay of other bidders, and therefore the final outcome;[17] this is illustrated by the example in Box 5.
(4) When there is incomplete information, sealed-bid formats lead bidders to place bids based on the expected (or average) externality, which is usually not equal to the realized externality once the auction has ended. This leads to inefficiencies even in symmetric settings. But not even the ascending-price auction is generally efficient,[18] and the comparison between sealed-bid and ascending auctions in terms of revenue raised is ambiguous.[19]
(5) Revenue maximization calls for special features such as entry fees that are dependent on the number of bidders, or payments to the seller even if there is no sale.

What does this mean in practical terms? The main policy issue on which we want to focus is the question of how much flexibility should be allowed in auction design. In deciding to whom and in what combination the goods should be allocated, should the bids offered by participants be the main consideration, or should there be significant restrictions placed in advance on the winning combinations that will be allowed? The next section discusses the trade-off behind this question in greater detail.

[16] See Jehiel and Moldovanu (1996) and Jehiel *et al.* (1996, 1999). Collusion is analysed by Caillaud and Jehiel (1998).

[17] There may also be free riding among bidders who each want to avoid paying the price of keeping a rival out of the market.

[18] Das Varma (2000) shows that the ascending-price auction is not equivalent to a sealed-bid format. The reason is that in the ascending format bidders can see who is still bidding and who left the auction, and adjust their beliefs accordingly.

[19] In a slightly different but related framework, Ettinger (2000) and Maasland and Onderstal (2001) have shown that first-price and second-price sealed-bid auctions are no longer revenue equivalent if losing bidders care about the amount of money paid by the winner.

Box 5. A takeover contest

Three firms bid for a fourth in a takeover contest.* Due to synergies, each bidding firm expects to make an extra profit of π if it wins the contest; if firm 1 wins, firm 2 expects a relative decrease in profits of α (and vice versa); firm 3 expects a smaller decrease in profits of γ if firm 1 or firm 2 wins; finally, firms 1 and 2 are unaffected if 3 wins.

From the firms' viewpoint (ignoring effects on consumers), the efficient buyer is firm 3 since the other firms do not expect to suffer a loss if 3 wins. Consider a first price sealed-bid auction: In one equilibrium, firm 3 indeed wins by bidding only π. But in another, firms 1 and 2, who are very afraid of each other, engage in a race and one of them wins by bidding up to $\pi + \alpha$. In that case, both firms suffer a loss of $-\alpha$ compared to the status quo! If firms 1 and 2 think that the expensive race is going to happen, they will have incentives to commit not to participate in the auction in the first place. For example, if firm 1 withdraws, 3 necessarily wins since it is willing to bid up to $\pi + \gamma$, while firm 2 is willing to bid only up to π (since 1 poses no danger anymore). Non-participation is better for firm 1 than the race with firm 2.

* Allocative externalities can easily explain the well-documented 'take-over premium'. Indeed a bidder may fear that he will incur a future loss (market share, profit, etc.) if another firm wins. Thus, bidders are willing to pay above the intrinsic value of the acquired firm in order to avoid future losses. See Jehiel and Moldovanu (2000a) for a simple model.

3.2. The tensions between value maximization, efficiency and revenue

Once an auction is embedded in a wider economic environment, we also need to take into account the welfare of parties that may be affected by the market outcome although they do not bid at the auction. In the sequel we refer to allocative efficiency when we consider all affected parties, while using the term *value maximization* for referring to an outcome that maximizes the welfare of the auction's bidders. The tensions between allocative efficiency, value maximization and revenue are magnified by the presence of externalities. In particular, the often repeated maxim 'Put the objects in the hand of those who value them most' is not a good guide for policy purposes, since the valuations of the bidders may come at the expense of other parties.

If the externalities are due to market structure considerations,[20] the notion of economic efficiency should not be solely based on considerations about firms' welfare; consumers' welfare should also be taken into account since it will be affected differently by the various possible outcomes of the auction. Since consumers usually do not participate in the auction, there is little hope that an auction design that does not

[20] We stress here the relations between market structure and allocative externalities alone. But the interplay of private information and allocative externalities naturally creates informational externalities. See Jehiel and Moldovanu (2000a, 2001a).

Box 6. Advantages and disadvantages of flexibility

There are four identical blocks of spectrum for sale, and five bidders. A bidder needs at least one block, but may buy up to two blocks. Each bidder submits bids for both one and two blocks. Blocks are allocated and payments are made according to a uniform price auction.* Suppose that each bidder would value having two blocks in a symmetric duopoly more than twice as much as having one block in a market with three operators (call its profits in the latter case π). One outcome of the auction is for two firms to buy two blocks each, paying a price of π for each. Flexibility (i.e., letting bidders decide whether to buy one or two blocks) leads to a configuration with two large operators. Whether or not this is efficient depends on the forces driving the comparison between the firms' valuation of one versus two blocks of spectrum in a three-firm versus two-firm market structure. If firms' willingness to bid for a second block is principally driven by the value of the additional productive capacity, then flexibility is desirable. If, on the other hand, it is driven mainly by the prospect of increased market power in duopoly, then flexibility may harm consumers. A comparison of the firms' *bids* alone will not yield an answer to this question; what is needed is an investigation of the underlying circumstances of the market in question.

* The equilibrium price is where demand equals the supply of five blocks. The winners are those bidders that bid above that price and all pay the same price per block.

explicitly incorporate their concerns will generate a high total welfare. Specifically, there is a risk that firms will use the auction as an instrument to increase market power, to the detriment of consumers. But a more thoughtful design may require restricting bids in some way, and may also generate lower revenue. For instance, restricting the number of licences that any one firm can buy will increase the intensity of competition in the final market in which the licences are used. This will reduce the total profits to be made in this market, and hence the amounts that firms are willing to bid for the licences which will enable them to participate. If the resulting competition is expected to be intense enough, the most efficient auction might even generate no revenue at all!

How much flexibility should be allowed in the presence of allocative externalities? Some flexibility is needed since it allows bidders to compete, to reveal how much they value the goods, and to combine them in ways that create economic value. But maximum flexibility may not be desirable, since it can be used by bidders to increase market power (possibly to the detriment of non-participants). Good design must carefully balance these two aspects, as the example in Box 6 shows. What is needed is a trade-off between the costs of market power and the benefits of efficient combination of assets. This is an issue of which the competition authorities have much experience in other fields (such as merger control), but the importance of which to the conduct of auctions has not yet been properly explored.

Table 1. European 3G licence allocation

Country	Population (millions)	Spectrum (MHz)	Mechanism	Licences	New entrants
Austria	7.9	145	Auction	6	2
Belgium	10.1	140	Auction	3	0
Denmark	5.2	155	Auction	4	1
Finland	5.3	140	Beauty contest	4	1
France	58.4	140	Beauty contest	2–3	0
Germany	82.0	145	Auction	6	2
Greece	10.5	140	Auction	3	0
Ireland	3.6	155	Beauty contest	2–3	0
Italy	57.4	125	Auction	5	1
Netherlands	15.3	145	Auction	5	0
Norway	4.4	140	Beauty contest	4	1
Portugal	9.9	140	Beauty contest	4	1
Spain	39.2	140	Beauty contest	4	1
Sweden	8.8	140	Beauty contest	4	1
Switzerland	7.0	140	Auction	4	1
UK	58.7	140	Auction	5	1

4. CASE STUDY: THE EUROPEAN UMTS LICENCE AUCTIONS[21]

Besides allocating spectrum packaged in several licences, the UMTS exercise has actively shaped the future telecommunications industry. The European licensing activity is summarized in Table 1. Several countries opted for so called 'beauty contests' in which licences were allocated on the basis of a bureaucratic procedure where criteria of evaluation include technical expertise, financial viability, network coverage, roll-out speed, etc. Such processes are not transparent, and are often prone to intense lobbying and political intervention. Assessing whether they fulfilled some pre-specified goals is a task tackled by Börgers and Dustmann in their paper in this issue. Other countries allocated licences via an auction procedure,[22] where the problems we have discussed played an important role. We want to address here several questions:

(1) What were the main goals of the UMTS auctions?
(2) What were the obstacles on the way?
(3) Why were several different designs used?
(4) Why did apparently related designs lead to different outcomes?
(5) Were the UMTS auctions successful?
(6) What issues deserve further thought?

[21] This section is based on and supplants our 2000 CEPR discussion paper 'The European UMTS Licence Auctions'. Later papers discussing various aspects of the UMTS auctions are: Börgers and Dustmann (2001), van Damme (2000), Grimm *et al.* (2001), Klemperer (2001).

[22] Practically all auctions are preceded by a stage where potential bidders have to qualify in light of technical, financial and other criteria.

4.1. Goals and obstacles

Licences are not clearly defined objects, but rather complex composites[23] subject to regulatory intervention. The main goal of the licensing exercise was economic efficiency. This means the maximization of the (possibly weighted) sum of consumers' and producers' surplus. Since future firm profits and consumers' rents are determined by the auction's outcome (and particularly by the number of licenced firms), a regulator must necessarily consider several alternative market scenarios.[24]

Consumers do not directly participate in spectrum auctions or beauty contests, and anticipating the expected consumers' surplus under various market constellations is difficult. Given high barriers to entry (due to network effects, huge fixed costs and spectrum scarcity) it is hardly conceivable that 'the market' itself could arrive at an optimal market structure by setting a 'right' price for licences during an auction (or its aftermath). Thus, the design must contain specific provisions that take care of consumers.

What should such provisions look like? Since standard oligopoly models predict (within reasonable ranges) that both consumers' surplus and overall efficiency increase with increased competition among firms, the creation of sufficient market competition becomes a proxy goal. This means that market entry should be actively encouraged as long as it is economically viable.[25] It is meaningful to focus on a value or revenue maximization only once this aspect has been taken care of.

A secondary goal of the UMTS auctions has been raising revenue for the government (a goal perhaps given exaggerated emphasis by popular media coverage). In Sections 2.3 and 3.2 we have emphasized the inherent tensions among various goals in multi-object auctions with market-structure considerations. Depending on the policy goals, the trade-offs can be resolved in many ways. Furthermore, similar auction formats may lead to different results if applied in different market architectures. To some extent, this fact alone explains why a single 'best' design that fits all situations does not exist.

4.1.1. Incumbents and entrants. Potential new entrants (firms that did not already operate a GSM network in the country concerned) faced two major difficulties:

(1) The fixed cost of setting up the infrastructure required for 3G services was very large. In contrast, some of the 2G incumbents' fixed costs were already sunk, since they could use significant parts of their already existing facilities (such as base station sites).

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[23] Some variables are: the number of licences and their capacities, technical limitations in order to avoid interference, licence duration, required network coverage, required roll-out speed, resale limitations, mandatory roaming agreements, mandatory site sharing and number portability. A decision on each variable may also affect the incumbent/entrant asymmetry discussed below.

[24] This aspect seemed to be very well understood by firms and analysts. For example, a major investment bank, estimated per licence values of €14.75 billion, 15.88 billion and 17.6 billion for a German symmetric market with six, five, or four firms, respectively. See WestLB Panmure (2000).

[25] Entry cannot be unambiguously beneficial since huge fixed costs need to be paid when new networks are built.

Table 2. UK valuations

Market structure	Firm type	Valuation (£ bn)
5 firms, 1 new entrant	Large incumbent with 3G licence	32.1
5 firms, 1 new entrant	Small incumbent with 3G licence	22.2
6 firms, 2 new entrants	Large incumbent without 3G licence	12.5
6 firms, 2 new entrants	Small incumbent without 3G licence	8.1
5 firms, 1 new entrant	New entrant with 3G licence	6.4

Table 3. German valuations

Market structure	Firm type	Valuation (€ bn)
4 firms, 0 new entrants	Large incumbent with 3G licence	88.4
5 firms, 1 new entrant	Large incumbent with 3G licence	78.3
6 firms, 2 new entrants	Large incumbent with 3G licence	47.8
5 firms, 1 new entrant	Large incumbent without 3G licence	36.3
5 firms, 1 new entrant	New entrant with 3G licence	14.5

(2) Since per-firm industry profits in oligopoly decrease in the number of active firms, incumbents were also driven by the wish to pre-empt entry,[26] in order to avoid further losses relative to the status quo. This translated into increased willingness to pay for licences and capacity. Thus, even if firms are comparable in terms of costs, know-how and financial strength, incumbents place higher values on licences than entrants do.[27] Hence, incumbents can bid higher than entrants, and we should expect that all GSM incumbents get licences unless some new entrants are significantly more efficient and therefore expect higher profits, or incumbents have tighter budget constraints. If potential new entrants perceive this disadvantage,[28] they might not bother to bid at all, or they might try to form consortia with incumbents. Both types of behaviour were observed and are likely to have an adverse effect on competitiveness and revenue. The need to attract entrants is the main concern of Klemperer (2000) and (2001).

Tables 2 and 3 illustrate how a major investment bank estimated licence values as a function of the various possible market constellations. While the numbers appear

[26] These and similar effects are well documented and understood, in particular in the area of innovation – see, for example, Gilbert and Newbery (1982), Krishna (1993) and Moldovanu and Sela (2001). In the context of spectrum licence auctions, see also Jehiel and Moldovanu (2000b).

[27] It is possible that special circumstances might lead an entrant to have a higher value than an incumbent. For example, a particular country licence may be the 'last piece in the puzzle' for a global firm who is then willing to pay more than a small local incumbent. But such features are hard to predict, and are subject to constant changes since firms form and break alliances, change business plans, etc.

[28] Klemperer (2000) points out that small perceived advantages ('toeholds') can be transformed into large advantages during the auction due to cautious behaviour in order to avoid the 'winner's curse'.

exaggerated with hindsight, it is obvious that market structure considerations and the incumbent/entrant asymmetry played a major role in that bank's estimates.

4.1.2. The number of licences. Encouraging entry was a major concern in many countries, and the main policy tool used to encourage entry was the number of licences awarded.[29] Most beauty contests adhered to a simple 'rule of thumb' formula that, in conjunction with stipulations allowing one licence at most per firm, made new entry almost inevitable:

Number of 3G Licences = Number of GSM Incumbents + 1

In most auctions a fixed number of licences was awarded, each endowed with a fixed capacity. Moreover, the number of licences was computed by the same formula as above (Holland and Denmark were major exceptions – see below for the details of those auctions). Thus, the choice of design was rather inflexible (and its main feature was determined by the regulator rather than by the auction itself), but it yielded auctions where bidders had unit demand. Most of the strategic problems arising in multi-unit demand frameworks (see Section 2) were avoided. A novel, flexible design was used in Germany and Austria: there both the number of licences and their capacity endowments were endogenously determined by the auction itself (see below for a description of the rule and an assessment). Also in the Greek design the number of licences depended on bidders' behaviour at the auction stage.

4.2. The main types of rules

The UK and Dutch designs (and also the Italian one to a large extent) revolved around a simultaneous multiple-round ascending auction for a fixed number of licences, each endowed with a fixed capacity.[30] As we saw in Section 2, when bidders have unit-demand, this design is good at maximizing the value of the outcome to the bidders.

Denmark had a fixed number of licences with a fixed capacity, but bidding was organized in a sealed-bid format.

4.2.1. The UK auction. The number of new 3G licences was hotly debated. An initial plan called for an ascending auction of four licences, complemented by a sealed-bid stage to be conducted when only five bidders remained active. One of the purposes of the sealed-bid stage was to allow an entrant to overbid an incumbent (which could not react anymore) in the uncertain one-shot sealed-bid procedure (see

[29] Several other measures accompanying the definition of licences (e.g., mandatory roaming agreements, manadatory site-sharing, installment payments for licence fees) tend to decrease the infrastructure costs (including the large financing costs). Since these measures usually have a stronger relative effect on entrants, they also influence the probability of successful entry through auctions.

[30] The simultaneous ascending approach and the concept of activity rules were introduced and widely used by the US Federal Communication Commission. See, for example, McMillan (1994), McAfee and McMillan (1996) and Milgrom (2000).

Klemperer, 2000 and 2002). After much subsequent deliberation about the 'right' number of licences, the designers fixed it to be five, one more than the number of incumbents; the final sealed-bid stage was abandoned as well. Moreover, only new entrants were allowed to bid on licence A, which was also endowed with the highest capacity, while bidding on licences B, C, D and E was open to all qualified bidders.

4.2.2. The Dutch auction. In contrast to the UK, the Dutch regulatory agency did not recognize that direct intervention in order to help new entrants was necessary. It organized an auction for five licences, where five was also the number of GSM incumbents.[31]

Bidders were required to bid at each round in order to remain in the auction. An exception was the possibility of using a 'pass' card in the first 30 rounds of the auction. Finally, there was a reserve price of about €50 million for each licence, but this price could be reduced after a stage in which no bids were made on that licence.

4.2.3. The Italian auction. There was a maximum of five identical licences. An interesting rule stipulated that, in case that there were only five or less bidders at the auction, the number of licences could be reduced to be one less than the number of bidders.[32]

In each round a bidder could make one bid and the five highest bids determined the current allocation (hence bids were not named to indicate a particular licence). Each winner was supposed to pay his own bid (and not, for example, the highest losing bid). The reserve price was about €2 billion per licence.

4.2.4. The Danish auction. Denmark planned to sell four identical licences, equal to the number of GSM incumbents. The Danish auction was the last one in Europe, and its regulators were probably aware of the problems caused by such a design (after having observed the Dutch outcome). To avoid the problems, the chosen design was a sealed-bid auction: all bidders had to submit sealed bids, and the top four bidders were awarded a licence. Each bidder had to pay the lowest winning bid (rather than, say, the highest losing bid).

4.2.5. The German and Austrian auctions. The German design (also used in Austria) allowed both for an endogenous number of licences and for endogenous capacity endowments.[33] In this respect, the design introduced a 'regulatory innovation'

[31] Of course, the Netherlands is a relatively small country, and it may be argued that five firms are sufficient. But then it is not clear to us why that particular auction was considered to be appropriate.

[32] This regulatory ingenuity was surpassed by a Turkish sequential design where the reserve price for a second licence was set to be equal to the selling price of the first licence. Consequently, the winner of the first licence bid very high, presumably more than expected duopoly profits. Since no second firm could have bid so high for the second licence, that licence was not sold, leaving the first winner with a monopoly!

[33] An earlier design which called for a fixed number of five licences had been abandoned because the flexible design was thought to offer 'a fair, undiscriminating, and efficient market solution to the problem of finding the optimal number of licences'.

towards greater flexibility. The rather complex procedure involved two consecutive auctions. The first auction allocated licences together with so-called 'duplex' or 'paired' spectrum frequencies. The second auction allocated paired spectrum that had not been sold at the first auction, together with additional 'unpaired' spectrum. Both auctions were of the 'simultaneous multiple-round ascending' type.

4.2.5.1. The licence auction. Bidders did not directly submit bids for licences. Instead, the auctioned objects were 12 blocks[34] of paired spectrum. The crucial design ingredient was as follows: A bidder obtained a licence only if he acquired at least two blocks, but a bidder was allowed to acquire (at most) three blocks. As a consequence, both the number of licenced firms and the capacity endowments were endogenous. The number of licenced firms could, in principle, vary between zero and six. If all blocks were sold there would be no less than four licences (which was equal to the number of GSM incumbents in both Germany and Austria).

The design was complemented by various activity rules stipulating such issues as reserve prices and minimum bid increments. Most importantly, at each round a bidder had to bid on at least two blocks (although the blocks were abstract and identical, bids carried name tags). Bidding on only two blocks at any round precluded bidding on three blocks at all later rounds.

4.2.5.2. The auction for additional capacity. The purpose of the second auction was to allocate additional capacity among the bidders that were licenced at the first auction. This means that only those bidders who had previously acquired at least two paired blocks of 2×5 MHz were allowed to participate.

Besides unsold paired blocks from the first auction, the second auction was supposed to allocate five additional unpaired blocks of 1×5 MHz each. Bidders could acquire any number of unpaired blocks, but were not allowed to acquire more than one paired block.

4.2.6. The Greek auction. Greece chose a two-stage auction procedure. In the first stage four licences each with 2×10 MHz paired spectrum and 5 MHz unpaired spectrum were offered via a sealed, pay your bid auction. If the first stage were to deliver less than four valid bids, a new auction would be organized with only three licences, and similarly until two licences remained. In the second stage, additional blocks of 2×5 MHz paired spectrum were offered (their number was identical to the number of stage one winners, and each bidder was allowed to buy at most two blocks).

[34] Blocks were 'abstract', i.e., the exact location of each block in the spectrum was determined *ex post*, to ensure that a bidder got adjacent blocks.

4.3. A stylized model

We use the following simple model in order to illustrate that market structure effects and the asymmetry between entrants and incumbents can go a long way towards explaining many of the observed outcomes. The main predictions of the model are:

(1) The relation between the number of licences and the number of GSM incumbents influences the equilibrium outcome to a large extent.
(2) Incumbents always get licenced.
(3) The flexible design used in Germany and Austria leads to complex gaming behaviour and has several equilibria with different outcomes. This makes actual outcomes hard to predict, and open to influence by various external factors.

Bidders in our model are characterized by the values they attach to feasible auction outcomes. We assume here for simplicity that all incumbents are symmetric, and that all potential entrants are symmetric. Moreover, we assume that values are common knowledge among bidders. We abstract here from the dynamic effects (in particular concerning tacit collusion) created by the use of ascending auctions.

The 'pure' economic value of a licence with a fixed capacity is given by the value of expected profits from operating the licence. This value increases if the licence is endowed with more capacity, and decreases if more firms are licenced.

An entrant's valuation is obtained by subtracting from the expected profit (which depends on the expected number of licenced firms) the fixed cost required to build a network. Besides the need to subtract lower infrastructure costs, an incumbent adds the expected profit that will be lost relative to status quo if that incumbent does not get a 3G licence.

We first use the model to look at the allocation of a fixed number of licences, and then apply it to the flexible format used in Germany and Austria.

4.3.1. A pre-determined number of licences (UK, Holland, Italy, Switzerland, Denmark, etc.). The main ingredients are as follows:

(1) The bidders are $n \geq 2$ special firms called 'incumbents' and $m \geq 2$ firms called 'entrants'. A fixed number $k \geq n$ of new 3G licences are auctioned.[35]
(2) Suppose that $s \leq k$ entrants acquire a new licence. We denote then by $\pi(n + s) \geq 0$ the per-firm expected profit in the future mobile telephony market for a bidder that acquires a 3G licence. This profit is a decreasing function of the total number of licenced firms in the market (e.g., new licencees and old incumbents).
(3) We denote by $-\gamma(n + s) \leq 0$ the expected loss (relative to the present status-quo) of a GSM incumbent that does not acquire a 3G licence.

[35] In all UMTS auctions the number of licences was not smaller than the number of GSM incumbents. For an analysis of the 'war of attrition' occurring when this assumption is not fulfilled, see Jehiel and Moldovanu (2000b).

(4) We denote by c_i and by c_e the fixed costs born by an incumbent and by an entrant, respectively, in order to build a 3G network. These costs are significant in relation to overall values. It is reasonable to assume that entrants' costs are higher than those of incumbents, but our results hold even if they are equal.

If s entrants acquire a licence, an incumbent that acquires a licence for a price p gets a payoff of $\pi(n + s) - p - c_i$. An incumbent who does not get a 3G licence has a payoff of $-\gamma(n + s)$. An entrant that acquires a 3G licence for a price p has a payoff of $\pi(n + s) - p - c_e$. An entrant that does not get a licence has a payoff of zero.

4.3.1.1. Analysis. Incumbents have higher valuations than new entrants. There are three reasons for this: First, incumbents are ready to pay an extra $\gamma(n + s)$ as compared with entrants because of the synergy between 2G and 3G licences. Secondly – since incumbents are already present in the market – the acquisition of a 3G licence by an incumbent is less damaging to the per-firm profits than the acquisition by an entrant. This is reflected by the fact that $\pi(n + s - 1) - \pi(n + s) > 0$. Thirdly, irrespectively of the market structure configuration, the fixed cost c_i of incumbents is likely to be lower than that of entrants c_e.

This fact leads to a number of conclusions (proofs are in the Appendix):

Conclusion 1: *If an entrant acquires a licence, then all incumbents must also acquire a licence.*

For the next conclusion we look at the non-trivial case where at least some entry is potentially profitable (i.e. we assume that $\pi(n + 1) - c_e \geq 0$):

Conclusion 2: *If the number of new licences equals the number of incumbents* n, *then all licences are bought by the incumbents and each one of them pays a price equal to the expected profit of a new entrant in a market with* n + *1 firms.*

For the next conclusion we assume again that the entry costs are not too high[36] (e.g., $\pi(k) - c_e \geq 0$):

Conclusion 3: *If the number of new licences* k *is higher than the number of incumbents* n, *then all incumbents get licenced, the other licences go to new entrants, and each licenced firm pays a price equal to the expected profit of a new entrant in a market with* k *firms.*

4.3.2. An endogenous number of licences (Germany, Austria). Here we make the following additional assumptions, and use them to show the conditions under which different market structures may emerge:

(1) There are four incumbents and two entrants. Twelve identical blocks are auctioned according to the rules detailed in Section 4.2.5.[37]

[36] It is possible that this assumption was not met in Belgium and Greece which did not manage to sell licences to newcomers although they were available.

[37] We focus here on the main first stage and ignore the additional strategic complexity induced by the presence of the second stage.

(2) If s new entrants acquire 3G licences, we denote by $\pi_q(n + s) \geq 0$ a bidder's value for q blocks, $q = 2,3$, as a function of the number of licenced firms in the market. We assume that π is decreasing in $n + s$ and increasing in q.

4.3.2.1. Analysis. We start again with a conclusion that identifies the advantage enjoyed by incumbents.

Conclusion 4: *If an entrant acquires enough capacity to obtain a licence (e.g., at least two blocks), then each of the four incumbents acquires at least that capacity as well.*

There are three main outcomes, differing by the number of licenced firms. The next three results determine under what conditions each outcome can emerge. The conditions relate the firms' valuations in various market constellations. The problem is that the conditions are not mutually exclusive. Hence, two or more different equilibria may co-exist for the same set of parameters. In an ascending auction setting, beliefs about which outcome will prevail can play a crucial role, and this opens the way to attempts by the firms to influence each others' beliefs.

Conclusion 5: *For an equilibrium with four licenced firms, the difference between the value of a large licence and that of a small licence in a four firm market must be no less than the per block profit of a licenced entrant (with either a small or large licence) in a five firm market.*[38]

The condition above says, roughly, that the marginal value of the third block for an incumbent is above the per-block value attached by entrants. Under such circumstances, all incumbents get a large three block licence. In a similar vein, the next two conclusions identify conditions for post-auction market with five or six firms.

Conclusion 6: *For an equilibrium with six licenced firms, a new entrant's expected profit in a market with six firms must be greater than twice the difference between the value of a large licence in a market with five firms and the value of a small licence in a market with six firms.*

Conclusion 7: *For an equilibrium with five licenced firms, the expected profit of an entrant with a small licence in a market with five firms must be greater than twice the difference between the value of a large licence in a market with four firms and the value of a small licence in a market with five firms.*

4.4. Outcomes

4.4.1. UK outcome. There were 13 participating bidders, and 150 rounds of bidding. The results are summarized in Tables 4 and 5. Four licences were acquired by the four GSM incumbents (with the largest unreserved licence going to Vodafone), while the reserved licence A was acquired by an entrant, TIW. Total revenue was

[38] In the Appendix we show that there exists an equilibrium where the only licenced firms are the four incumbents.

Table 4. Outcome, UK auction

UK licence	Bandwidth MHz	Holder	Bid (£ bn)	Bid (€ bn)	Price/MHz (€ m)	Price/Pop (€)
A	$2 \times 15 + 1 \times 5$	TIW	4.38	7.23	206	126
B	2×15	Vodafone*	5.96	9.84	328	172
C	$2 \times 10 + 1 \times 5$	BT*	4.03	6.65	266	116
D	$2 \times 10 + 1 \times 5$	One2One*	4.00	6.60	264	115
E	$2 \times 10 + 1 \times 5$	Orange*	4.10	6.76	274	118
Total	140		22.47	37.08		
Average	28		4.49	7.41	264	129.4

Note: * indicates GSM incumbents.

Table 5. Final bids, UK auction

UK bidders	Backers	Last bid (£ bn)	Last bid (€ bn)
Vodafone*	Vodafone	5.96	9.84
BT3G*	BT	4.03	6.65
One2One*	DT	4.00	6.60
Orange*	Orange	4.10	6.76
Average incumbent		4.52	7.46
TIW*	TIW	4.38	7.23
NTL	NTL,FT	3.97	6.55
SpectrumCo	Sonera	2.10	3.47
Epsilon Tele. com	Nomura	2.07	3.42
3GUK	Eircom	2.00	3.30
Crescent Wireless	Global Crossing	1.82	3.00
Global Wireless	One.Tel	2.18	3.60
Telefonica UK	Telefonica	3.67	6.05
WorldCom Wireless	MCI Worldcom	3.17	5.24
Average entrant		2.82	4.65
Average		3.34	5.51

Notes: * indicates a winning bidder.

£22.5 billion. The outcome is the one predicted by Conclusion 3, where the number of licences was higher than the number of incumbents, and where all incumbents got licenced. In particular, Table 5 displays the final bids of all 13 bidders and shows that the average incumbent bid was much higher than the average entrant bid.

4.4.2. Dutch outcome. There were six bidders (five incumbents, one entrant). The results are summarized in Table 6. The five licences were acquired by the five GSM incumbents (with the large licences going to KPN and to Vodafone's subsidiary, Libertel). Total revenue was a relatively low €2.7 billion. These features agree well with the prediction of Conclusion 2, where the number of licences is equal to the number of incumbents, and where no entrants are licenced. The only participating new entrant, Versatel, stepped out very early claiming that it had been threatened by

Table 6. Outcome, Dutch auction

Dutch licence	Bandwidth MHz	Holder	Bid (€ bn)	Price/MHz (€ m)	Price/Pop (€)
A	2 × 15	Libertel (Vodafone)*	0.713	23.76	44.84
B	2 × 15	KPN*	0.711	23.70	44.71
C	2 × 10	Dutchtone (FT)*	0.435	21.75	27.35
D	2 × 10	Telfort (BT)*	0.430	21.50	27.04
E	2 × 10	3G Blue (DT, etc.)*	0.394	19.70	24.77
Total	120		2.683		
Average	24		0.536	22.35	33.74

Note: * indicates GSM incumbents.

Table 7. Outcome, Italian auction

Italy licence	Bandwidth MHz	Holder	Bid (€ bn)	Price/MHz (€ m)	Price/Pop (€)
A	2 × 10 + 1 × 5	Omnitel* (Vodafone)	2.448	97.92	42.64
B	2 × 10 + 1 × 5	Tim* (TI)	2.417	96.68	42.10
C	2 × 10 + 1 × 5	Wind* (FT)	2.428	97.12	42.29
D	2 × 10 + 1 × 5	Andala	2.428	97.12	42.29
E	2 × 10 + 1 × 5	Ipse	2.443	97.72	42.56
Total	120		12.164		
Average	24		2.432	97.31	42.37

Notes: * indicates GSM incumbents. Blu* left the auction with a last bid of €2.319 bn.

an incumbent (BT's subsidiary, Telfort). This disappointing but predictable outcome was the subject of a parliamentary inquiry.

4.4.3. Italian outcome. The number of bidders (four incumbents and two new potential entrants) was equal to the *a priori* maximal number of licences plus one. Hence, the number of licences was not reduced and remained fixed at five, and at least one new entry was inevitable. The auction ended after 11 rounds, after Blu, the smallest and weakest incumbent, dropped out. The remaining five firms paid about €2.4 billion per licence (see Table 7). This outcome is inconsistent with Conclusion 1, and the likely explanation is the asymmetry among incumbents. Apparently, the weak Blu gave up following serious conflicts about financing between the Italian shareholders and the main foreign backer, BT. The government was furious about the early end of the auction, and accused Blu and other firms of manipulation.[39] It is possible that, besides Blu's management and organization problems, the relatively generous stipulations made for entrants contributed to the auction's outcome.

[39] The idea was that Blu had been possibly 'asked' to take part in the auction by other firms, thus keeping the number of licences at five.

Table 8. Bidders in the German auction

German bidders	Backers
T-Mobil*	Deutsche Telekom
Mannesmann*	Vodafone
E-Plus*	KPN, Hutchison
VIAG Interkom*	VIAG, BT
Mobilcom Multimedia	Mobilcom, France Telecom
Group 3G	Telefonica, Sonera
Debitel	Swisscom

Note: * indicates GSM incumbents.

4.4.4. Danish outcome. The sealed-bid procedure introduced a lot of uncertainty in the auction since firms could not react to bids placed by competitors. In particular, one entrant bid more than an incumbent – besides the peculiar case of Blu in Italy (see above), this is indeed the only instance when an incumbent was not successful. This phenomenon is also inconsistent with Conclusion 1; the likely explanation is the presence of incomplete information about valuations in conjunction with the one-shot bidding in the sealed-bid auction.

4.4.5. German outcome. A design that allows for a flexible number of licences and a flexible capacity endowment for these licences makes the bidders' valuations completely dependent on their conjectures about the behaviour of others. It thereby opens the door to complex gaming behaviour, since bidders may have different beliefs about which one of the possible equilibria will prevail. Besides the allocative externalities, the design induced multi-unit demand, exposure and demand-reduction aspects. The government risked a concentrated market[40] because incumbents could exploit the flexibility of the auction format for pre-emptive motives.[41] The revenue was likely to be high because of the extra willingness to pay for inducing a more concentrated market. Luckily for the government, the outcome (summarized in Tables 8 and 9) yielded both high revenue and two new entries.

There were only seven bidders (including four GSM incumbents), after six other qualified bidders withdrew from the auction. The licenced firms were the four incumbents and two new entrants (one of them already operating as service provider). Each licenced firm acquired two blocks of paired spectrum at the main licence auction, and each licence cost approximately €8.4 billion (or €4.2 billion per block).

The most interesting thing occurred after one of the potential entrants, Debitel, left the auction in round 125 at a price level of €2.5 billion per block. Since six firms

[40] There were other hurdles for new entrants: roaming agreements were not mandatory; full payment for the licences was required ten days after the auction; each licenced firm needed to build an independent network.

[41] We criticized this feature in a previous working paper called 'A Critique of the Planned Rules for the German UMTS/IMT-2000 Licence Auction'.

Table 9. Outcome, German auction

Germany licence	Bandwidth MHz	Holder	Bid I. stage (€ bn)	Bid II. stage (€ bn)	Price/Mhz (€ m)	Price/Pop (€)
1	$2 \times 10 + 1 \times 5$	Mannesmann*	8.42	0.061	339	103
2	$2 \times 10 + 1 \times 5$	T-Mobil*	8.47	0.062	341	104
3	$2 \times 10 + 1 \times 5$#	E-Plus*	8.39	0.037	337	103
4	2×10	Viag Interkom*	8.44		422	103
5	$2 \times 10 + 1 \times 5$	Mobilcom*	8.36	0.061	336	102
6	$2 \times 10 + 1 \times 5$	Group 3G	8.40	0.062	338	103
Total	145		50.51	0.286		
Average	20		8.42	0.057	352	103

Notes: Debitel left the first stage with a last bid of €5 bn. * indicates GSM incumbents. # indicates unpaired block of lesser quality.

were left bidding for a maximum of six licences, the auction could have stopped immediately. Instead, the remaining firms (and in particular the two large incumbents) continued bidding in order to acquire more capacity. But no other firm was willing to quit and the race for more capacity stopped in round 173. Compared to round 125, there was *no change* in the physical allocation, but firms were, collectively, *€20 billion poorer*![42]

Ewerhart and Moldovanu (2001) explain the bizarre outcome via equilibrium analysis in an ascending auction with incomplete information based on the model outlined in Section 4.3.2: The capacity limitation rules implies that in any possible auction outcome which includes entry there is at least one new firm that has acquired exactly the minimum mandated two blocks (Conclusion 4 implies that this must be an entrant). If this firm loses one block, then it loses the entire licence. Thus, by acquiring one block of capacity in excess of the minimum two blocks, an incumbent gets substantial extra value because it can deny an entire licence to a new entrant. These strong, artificially created complementarities among blocks led to an exposure problem similar to the one discussed in Section 2.2. Ewerhart and Moldovanu also show that, even in an equilibrium in which firms are behaving rationally, they may bid in a way that leaves some probability of regretting the outcome after the event. This is a reasonable explanation for what happened in reality since pre-emption failed; the final outcome could have been achieved at much lower cost.

Why did pre-emption ultimately fail? Besides the growing pressure from stockmarkets and bond-rating agencies during the auction, note that there were only two financially strong incumbents. Since prices were already high when Debitel stepped out, at least one entry looked plausible. As one entry was likely to occur, the value of

[42] In the second stage five firms (three incumbents and two entrants) each acquired an additional block of unpaired spectrum. There was no serious bidding and it seems that the enormous price paid at the first stage did not allow further flexibility. In particular, the smallest incumbent's budget constraint did not leave any room for additional bidding.

avoiding a second entry was somewhat reduced (and possibly strategic demand-reduction then occurred).[43]

Towards the end of the auction there was clear signalling activity among the two large incumbents who tried to sort out whether to continue bidding in order to reduce the number of entrants. Mannesmann made several bids where the smallest free digit (i.e., taking into account the rules that allowed only bids in multiples of DM 100 000) was six, suggesting that it was finally ready to accept an outcome with six firms. Initially, DT responded with bids ending in five, suggesting that it was willing to bid even higher in order to reduce the number of licences to five.[44]

Finally, it is interesting to note that some firms plan to operate via a shared network, in blatant disregard of the licences' terms which state that a firm which does not roll out an independent network must return the licence and the attached spectrum. Klaus-Dieter Scheurle, head of Reg-TP at the time of the auction thinks now that six networks are an 'illusion'. The new entrants are indeed in trouble: Mobilcom (backed by France Telecom) is practically bankrupt, while Telefonica-Sonera has discontinued its operation in Germany.

4.4.6. Austrian outcome. In Austria there were exactly six bidders (four of them GSM incumbents) for a maximum of six licences. Hence, in principle, the licence auction could have ended immediately, at the reserve price (€100 million per licence). But the licence auction continued for another 16 rounds, before stopping with six licenced firms, each paying €120 million per licence (see Table 10). Hence, about €120 million have been again spent for 'nothing' while firms tried to buy more capacity and reduce the number of licences. After observing the German outcome, firms probably understood the inherent danger of exposure, and quickly reduced demand.[45]

4.4.7. Other auctions. Switzerland, Belgium and Greece all auctioned four licences, one more than the number of GSM incumbents. The Swiss auction attracted only four bidders and the licences sold close to the low reserve prices. All incumbents were licenced. The Belgian and Greek auctions attracted only the respective three incumbents, and the licences were also sold at the reserve prices, while one licence remained unsold. But, per capita, the Belgian and Greek reserve prices were higher than the Swiss one.

[43] Another intriguing explanation for the level of prices arises by noting that DT is majority owned by the German government. Hence, by driving up prices, DT clearly served the interest of the auctioneer (while the price it paid itself can be partly seen as a transfer from one government pocket to another). A lawsuit was brought by one of the small incumbents, but it was not further pursued.

[44] Jehiel and Moldovanu (2000b) analyse how the possibility of tacit collusion is affected by the relation between the number of incumbents and the number of licences. From the point of view of incumbents, sustaining the best collusive outcome is more difficult (and may fail) if there is no focal, symmetric method which allows the incumbents to share the pre-emption cost. In such a case there might be free-riding among incumbents, since each one of them prefers to let other incumbents pay a higher share of the cost.

[45] Some commentators suggested that the rounds of bidding were just 'pro-forma' in order not to give the impression that some collusive agreement among firms was in place.

Table 10. Outcome, Austrian auction

Austria licence	Bandwidth MHz	Holder	Bid I. stage (€ m)	Bid II. stage (€ m)	Price/Mhz (€ m)	Price/Pop (€)
1	2 × 10	3G Mobile	117		6	14.80
2	2 × 10	Connect* (Orange, etc.)	120		5.56	15.18
3	2 × 10 + 1 × 5	Hutchison 3G	114	25	5.66	17.59
4	2 × 10 + 2 × 5	max.mobil* (DT)	119	51	5.65	21.51
5	2 × 10	Mannesmann 3G#	113		5.73	20.00
6	2 × 10 + 2 × 5	Mobilkom* (TI)	121	51		21.77
Total	145		704	127	5.74	
Average	24.16		117.3	21.16		18.47

Notes: * indicates GSM incumbents. # Mannesmann was already a services provider, but without own network.

4.5. Assessment and food for thought

The results of the UMTS auctions present a great deal of variance. Some of it can be explained by country-specific differences in the mobile telephony market (such as the incumbents' situation in the GSM market) and some by timing (e.g., the burst of the technology 'bubble' during the auctions). In a number of instances, the UMTS auction design influenced the outcome, in particular through the measures taken (or not taken) to alleviate the incumbent/entrant asymmetry.

Several observers have assessed the success of the UMTS auction based (almost solely) on the revenue dimension.[46] Since the main goal of all auctions has been efficiency, and since, as argued before, there are clear tensions between efficiency and revenue, we find this rather problematic. Moreover it is possible that the dramatic change in market sentiment during the auctions (both in general and specifically towards the value of UMTS) constituted a first order effect with respect to revenue considerations. Of course, some of the auctions (e.g., Holland, Switzerland) failed to raise decent revenues also because of relatively 'prosaic' design mistakes such as setting very low reserve prices. Italy's auction did not run smoothly either, but revenue was higher only because reserve prices were relatively high.

Since the UMTS networks are not yet realized, it is too early to assess the various auctions on the efficiency dimension. In contrast to revenue, the physical allocation of licences was to a larger extent under the control of the designers, and at the moment the only criterion that can be reliably assessed is the number of licences and the relation to the number of GSM incumbents.

The UK design was particularly favourable to new entrants since it reserved the largest licence to such firms. As we argued before, Holland's auction was flawed

[46] It has been claimed that the revenue collected at auctions is a form of taxation that is less distorting than other, more traditional methods.

mainly because it sold the same number of licences as incumbents. But Holland is a small country, and it already had five GSM incumbents. It is impossible to argue that, from the point of view of efficiency, the Dutch outcome with five UMTS licencees is worse than the UK one, also with five licencees. Switzerland used the 'Incumbents + 1' formula and got a new entrant. Again, it is hard to argue that, for such a small country, the allocative efficiency is worse than that in the UK (even if revenue was low). The Danish sealed-bid auction displaced a GSM incumbent while achieving decent revenue (given the late timing of the auction). There are scenarios where the displacement of an incumbent is inefficient if it stems from a bidding mistake which cannot be corrected in the sealed-bid auction, and if the incumbents' investment in the GSM technology cannot be smoothly used in the future. Finally, one cannot argue that the outcome of the Belgian and Greek auction is inefficient because no entry occurred – there a licence was available for new entrants but there were no willing bidders – the expected infrastructure costs were probably higher than expected profits in these small markets.

Pre-emption effects clearly played a role during the German auction. But the design strategy was risky and ultimately led to an outcome clearly regretted by all winners. In our view, this disadvantage outweighs the benefit stemming from the more flexible design. A small modification, with flexibility between five and six licences only (which would have ensured entry) would seem to us to have been preferable.

We see four interesting questions where more economic thinking is needed:

(1) Several firms were interested in building wide networks with full European coverage. Hence, they perceived strong complementarities among licences in different countries. But the UMTS licensing process was sequential, and spread over more than two years (with timing becoming a non-trivial determinant of the outcome). It makes sense to think both about EU-wide licences and about more uniform timing of allocation.

(2) There is no market in spectrum at the moment. It is not very likely that resales will solve all allocative problems, no matter how the allocation was achieved.[47] But there is no reason to forbid some regulated form of secondary market in order to adjust to a rapidly changing environment during the many years when licences are valid. Auctions without a secondary market may yield misallocations if valuations for licences are hard to assess with a reasonable degree of confidence. In such uncertain contexts, is it preferable to postpone the auction until superior knowledge about the technology is available, or is it preferable to go for the licence auction as soon as possible while letting a secondary market deal with the necessary adjustments?

[47] Jehiel and Moldovanu (1999) show that resale markets remove the final outcome's dependency on the initial allocation of property rights but need not lead to an efficient allocation if the parties in each exchange cannot write contracts over the entire future use of the resources.

(3) Is it possible to base the deliberations about how much spectrum is allocated for each application predominantly on economic (rather than technical) aspects? In particular, does it make sense to allocate spectrum without mandating a specific use, and let the market 'work'? The 140 MHz made available for 3G has been determined by the International Telecommunication Union (ITU) in a bureaucratic procedure which does not involve pricing of the various alternative uses of spectrum. In other words, the scarcity that has been created for 3G spectrum may be artificial.

(4) Auctions function well if the designer can commit to the rules in advance, including the exact definition of what is being sold. In several countries firms are now demanding changes to the rules about network and site-sharing, roll-over speed, coverage requirements, etc. Giving in to such demands may undermine the credibility of future exercises. But, on the other hand, there is no doubt that several parameters have changed (and will continue to change quickly) and therefore some adjustment will probably be needed. The trade-off between credibility and allowing scope for renegotiation after the event is complex, and it is worth analysing the advantages/disadvantages of flexibility in that particular dimension.

5. POLICY RECOMMENDATIONS

We conclude this paper with a brief summary of our main conclusions and policy recommendations:

(1) If the auction's allocation influences the future interaction among bidders, this will influence behaviour at the bidding stage. In such environments serious design calls for an integrated approach that combines the insights of auction theory with the traditional concerns of regulation and competition policy. In particular, more flexible auction formats do not necessarily improve efficiency. Policymakers concerned with consumers' welfare need to assess the range of acceptable market structures and clearly specify the expected regulatory regime. The flexibility of the auction format can then be restricted so that the outcome lies in this range.

(2) Multi-object auctions raise a large number of difficulties. Allocative or informational externalities, multi-unit demand, heterogeneity and complementarities induce complex demand or supply functions which are difficult to represent in reasonably simple auction formats. Such formats necessarily restrict bidders in some aspects, creating complex strategic effects that may reduce the auction's performance. For example, whether the advantages of combinatorial bidding in a multi-object auction with complementarities outweigh the disadvantages stemming from complexity needs to be assessed in the light of the circumstances of each case. Combinatorial bidding is desirable, roughly speaking, when the gains in productive value from combining objects are more important than the incentives for excluding competitors (this is the kind of trade-off that competition authorities

have some experience of assessing in other contexts such as mergers and co-operative agreements). Experimental investigations tailored to assess various features can assist the design process.

(3) In multi-object auctions and in auctions with externalities, there may be severe conflicts between goals such as efficiency, value maximization to the bidders, and the maximization of revenue to the seller. A clear specification of goals is crucial for successful design. If efficiency matters, it may be necessary to accept consciously the likelihood of lower revenues. Even if estimates about welfare or consumers' surplus are not immediately available after the auction, reasonable indicators of the auctions' success need to include the expected degree of competitiveness in the market structure shaped at the auction stage.

Discussion

Marco Ottaviani
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In this paper, Jehiel and Moldovanu apply recent developments in auction theory to the design of radio spectrum licence auctions. The presence of interdependent signals and valuations, multi-unit demand and downstream interaction crucially affect the outcome and performance of auctions. When the winning bidders compete in the downstream market, a flexible auction design that allows bidders to determine the number of licences tends to result in overly concentrated market structure.

Jehiel and Moldovanu presuppose that auctions are the best allocation mechanism. This discussion, in contrast, addresses the broader question of when a policymaker should be advised to adopt an auction procedure. Focus for simplicity on the standard case of a seller of an object who does not know of the identity of the buyer with the highest value. By auctioning the object, this seller creates competition among potential buyers and can extract the second highest value. If, instead, the seller knows who has the highest value, it can bargain with the buyer, and should end up selling the good at an even higher price. Actually this argument is somewhat flawed, as the seller who knows the highest value can always adopt an auction with reserve price equal to that value. Nevertheless, if formal auction procedures are costly, we would expect them to be typically adopted when the seller has limited knowledge of demand. From this illustration, one could conclude that auctions are a desirable market-based way of obtaining information the seller does not have.

To understand better when auctions are desirable at a more fundamental level, it is worth defining them and their alternatives more clearly. In an auction the seller commits to clear rules. The details of the rules for the European 3G auctions were fully specified and required much preparatory work, but essentially all these auctions prescribed allocation of licences to the qualified bidders submitting the highest monetary bid. In these auctions, bids were one-dimensional. In many other auction-like procurement and allocation procedures, auctioneers seek multi-dimensional bids that are then aggregated according to publicly announced scoring rules (though sometimes verification of non-monetary aspects of bids requires considerable subjective judgment).

In my opinion, governments as well as large or regulated companies often opt to use auctions because they are transparent allocation procedures, widely thought to reduce the scope for discretion and favouritism. Unless some categories of bidders are explicitly granted a different status, the auctioneer cannot discriminate in favour or against a bidder. The main alternatives to auctions are bureaucratic procedures and beauty contests, in which negotiations are typically not very transparent and involve subjective judgment.

As stressed in the economics literature on mechanism design and optimal auctions (see Myerson, 1981), standard auctions are optimal allocation mechanisms for some important but special settings in which bidders have independent signals. By committing to a mechanism that typically induces *ex post* inefficiencies, the auctioneer gains bargaining power vis-à-vis the bidders thereby maximizing *ex ante* revenues (albeit at the cost of foregoing the flexibility of reacting to new information as it becomes available). The insights and techniques of mechanism design can also be applied to derive efficient (rather than revenue maximizing) auctions in more general environments.

In conclusion, auctions are characterized by the seller's commitment that competition will take place according to pre-defined rules and with a transparent procedure. Transparency is socially desirable and commitment is good for the seller. This is why economists typically advise governments to use general auction procedures (broadly interpreted to allow for multi-dimensional bids and rich rules) rather than other less structured and more discretionary allocation methods.

Clearly, this does not imply that standard auctions are to be adopted in all situations. On the contrary, careful auction design is essential in most situations. Good auction design is based on a careful analysis of the particular 'economics of demand' and the induced market structure. Unfortunately, the policymakers often have rather limited information on the prevalence of private or common values, the amount of information of the bidders, the complementary or substitutability of the units, the nature of the externalities, the presence of market power and the details of downstream competition.

If similar objects are auctioned repeatedly, as for example in the case of auctions for gas and electricity transmission capacity, information from past bidding behaviour and downstream market outcomes can be used to infer bidders' valuations. It is worth noting that different auction rules result in qualitatively different revelation of information about these valuations. For example, in an open ascending auction the winning bids are equalized in equilibrium. In this case, the auctioneer cannot learn whether the underlying values of the winner are heterogeneous. In a closed simultaneous auction, bidders' dispersion can instead be used to infer heterogeneity in bidders' valuations.

It is natural to wonder what other means would allow the policymaker to obtain such information from the market participants. In the case of 3G licences, many governments conducted extensive consultations with industry participants to collect information on possible and efficient market structures. It would be desirable to conduct these consultations in a transparent way and to embed them into the general allocation mechanism in order to gain commitment power. More work is needed in the area of mechanism design to develop and test relatively simple and robust mechanisms that allows the policymaker to obtain and automatically incorporate this information in the allocation procedure.

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University of Bristol

This paper very nicely presents the complexities involved in auction design of interdependent objects. As the authors point out, such objects have been the subject of several recent high-profile auctions and, indeed, are likely to be the subject of more, as governments attempt to use economics to allocate scarce resources. So, understanding these difficult issues is a key requirement for sensible policy development in this area.

The paper helps us understand the key parameters that need to be considered in such auctions, both by outlining recent theoretical contributions and by referring to the experience of recent European spectrum auctions. Perhaps what emerges most strongly is the complexity of the issues. Other writers have already, in the context of the European spectrum auctions, drawn attention to the fact that 'one size definitely does not fit all' for such auctions. Jehiel and Moldovanu add to this and argue that if the auction allocation influences future interactions among bidders, economists will have to combine the insights of auction theory with the market structure concerns of regulation and competition policy. Further, in auctions like the spectrum auctions, there are likely to be conflicts between different goals that the government might legitimately hold. That the world is complex may not come as much surprise to the economist used to giving policy advice, but what is extremely helpful is to have a clear outline of the economic issues that need to be tackled in dealing with these cases.

I do have some concerns about some of the specific suggestions made with respect to spectrum at the end of the paper. The authors intimate that the sequential nature of the UMTS licensing process raised problems and suggest Europe-wide licences. They are not specific on what these problems are, but one might be that those who win beauty contests in one country have deep pockets and can more easily win at auctions in another country. However, there is no evidence that this is what actually happened. The incumbents in countries that had beauty contests (e.g. Spain, Finland, Sweden) did not appear to be any more or less successful in auctions than others. The pan-European operators (DT, France Telecom and Vodafone) bid in both auctions and beauty contests.

The authors also suggest secondary trading of spectrum. In fact, this is not a new idea: there are currently UK proposals for such a market, and it is done in New Zealand and Australia and the US is looking at leasing arrangements. This area doesn't seem to me so much to require more research as to have serious thinking about implementation.

Finally, the call to base spectrum allocations on economic factors could be seen as rather naïve, given that these are decided at conventions at which 200 or so countries are represented. However, there are signs of moves in this direction. For example, the allocations for 3G (and there is more to be released in 2005) were largely determined by the amounts asked for by the international industry group. This may give economists hope that our tools will be used more by governments.

Panel discussion

Benny Moldovanu replied to Marco Ottaviani that the cost and benefits of commitment needed to be further discussed in further research, but he remarked that the same applied to beauty contests as well. Tilman Börgers urged the authors to discuss alternative auction designs. He also wanted more evidence from the authors on how well their proposed auction models worked in practice. He disagreed with their view that the auction design for the UK was successful, because this view ignored the incentives to remain an outsider or small firm. He challenged the view that much can be learned from experiments because results of experiments before the auctions were quite different from the results of the auctions themselves. Benny Moldovanu replied that this was not surprising because these experiments were conducted by parties with a biased interest.

Eric Bartelsman was interested in further discussion of military versus private use of the spectrum and the use of the spectrum for alternative broadcast technologies. Benny Moldovanu agreed that it was not clear why the use of the spectrum should be mandated. Gilles Saint-Paul asked how scarce the spectrum is as a resource and why a quantity rather than a price mechanism is used for its allocation. Benny Moldovanu replied that the spectrum is defined to be scarce by the government and military, and its scarcity has not been given a convincing economic rationale.

Monika Schnitzer was unconvinced by the arguments against flexibility in the number of licences. In the example given, the efficient number of licences is already known to the government. If one wanted to understand the benefits of flexibility, it would be crucial to incorporate uncertainty into the analysis. Moreover, she referred to the German example to illustrate the problem of strategic bidding with a deterministic number of licences. Deutsche Telecom had bid for an additional licence in order to drive up the price of licences. This was intended to drive smaller firms into bankruptcy later on. Benny Moldovanu replied that the alternative to having the number of licences determined by the government would be that the number was determined by firms. He was skeptical whether firms had better knowledge than the government what the right number would be. Philippe Jehiel added that the main insight of their analysis was that the market could not be expected to reveal this information at least through a flexible and simple bidding procedure.

Gilles Saint-Paul pointed out that high bids for licences show how hard it is for firms to evaluate the return of a licence in advance. In this context one might wonder whether auctions are the best mechanism to implement the right number of licences and induce the right learning about the technology. The danger is of attracting those firms who falsely attribute too much value to the licence.

Paul Klemperer pointed out that the model's assumption of free entry was restrictive and empirically implausible. Some entrants needed to be persuaded to enter the market. Furthermore, not all entrants are the same. The UK auction design had been explicitly motivated by the wish to attract entrants who might not have been able to bid on an equal footing with incumbents. Moreover, timing was crucial because the stock market performance mattered for the revenues of the auctions. As the stock market declined so did the number of bidders in the respective countries. The UK government had thought about this issue and tried to get ahead of the game. Philippe Jehiel claimed that it is not at all clear that the best way to attract participants is through the choice of the auction format. Proper advertising campaigns or proper timing choices may be at least as important.

APPENDIX

For all proofs we assume that bids can be made in multiples of a minimum increment denoted by ε, and we assume that ε is small enough in relation to the other parameters.[48]

In our framework, simultaneous ascending auctions have, for each set of parameters, many equilibria, resulting in different allocations and payoffs. Moreover, the equilibrium number of licenced firms may vary with the parameters. Besides various technical details associated with the simultaneous ascending auction (which play no role for our argument),[49] the multiplicity is also caused by the fact that valuations are endogenous and depend on expectations about the final number of licenced firms.

We assume below that the relevant equilibrium bids are all above the reserve price. Moreover, we consider below only equilibria where identical objects (licences or capacity blocks) are sold at the same price, modulo minimum bid increments.[50]

Proof of Conclusion 1:[51] Consider an equilibrium where $s \geq 1$ new entrants are licenced, and consider a new entrant who payed $p \geq 0$ for its licence (call this licence A). Since the

[48] To be precise, this means that strict inequalities among various valuations and high bids are not reversed if up to three minimum increments are added or subtracted to one side of the inequality.

[49] For example, we ignore any coordination problems such as 'who bids on what blocks'.

[50] One can construct equilibria where this assumption is not fulfilled, but this symmetry is a reasonable working assumption. Moreover, this feature is considered to be a big advantage of the simultaneous ascending auction.

[51] We implicitly use below the only tie-breaking rule that is consistent with a more general formulation where valuations are continuously distributed and strictly higher valuations lead to strictly higher bids: a new entrant cannot win a licence if there is an incumbent who bids at least as high as the entrant on that block.

entrant's payoff must be non-negative, we obtain that $\pi(n + s) - p - c_e \geq 0$, which is equivalent to $p \leq \pi(n + s) - c_e$. Assume, by contradiction, that an incumbent does not get a licence. In particular, this means that this incumbent bids less than p on licence A, and that this incumbent has a payoff of $-\gamma(n + s)$. Consider now a deviation where the incumbent bids $p + \varepsilon$ on the above licence. With such a strategy, his payoff becomes $\pi(n + s - 1) - (p + \varepsilon) - c_i \geq \pi(n + s - 1) - (\pi(n + s) - c_e) - \varepsilon - c_i > c_e - c_i - \varepsilon$ (because $\pi(n + s - 1) > \pi(n + s)$) and $c_e - c_i - \varepsilon > 0 \geq -\gamma(n + s)$. Hence, the deviation is profitable, a contradiction to the assumption that we considered an equilibrium.

Proof of Conclusion 2: Consider the following strategies: each entrant bids $\pi(n + 1) - c_e$ and each incumbent bids $\pi(n + 1) - c_e + \varepsilon$. If the above strategies are played, entrants get a payoff of zero and incumbents get a payoff of $\pi(n) - \pi(n + 1) + c_e - c_i - \varepsilon > 0$. The above strategies form an equilibrium because: (1) Given that all other incumbents bid above $\pi(n + 1) - c_e$, an incumbent i has no incentives to bid below that since this means leaving a licence to an entrant, yielding a payoff of $-\gamma(n + 1) \leq 0$. (2) Given that an entrant expects that all other licences go to incumbents, the value of a licence to an entrant is $\pi(n + 1) - c_e$.

Proof of Conclusion 3: The following strategies define an equilibrium: each entrant bids $\pi(k) - c_e$ and each incumbent bids $\pi(k) - c_e + \varepsilon$. If the above strategies are played, entrants (whether licenced or not!) get a payoff of zero, and incumbents get a payoff of $c_e - c_i - \varepsilon > 0$. The above strategies form an equilibrium because: (1) Given that all other bidders bid at least $\pi(k) - c_e$, an incumbent i has no incentives to bid below that since this means leaving a licence to an entrant, yielding a payoff of $-\gamma(k + 1) \leq 0$. (2) Given that an entrant expects that n out of k licences go to incumbents, the value of a licence to an entrant is $\pi(k) - c_e$.

Proof of Conclusion 4: Consider an equilibrium where $n + s$ firms are licenced, including a new entrant who obtains q blocks, $q \geq 2$, by paying b per block. Since the entrant's payoff must be non-negative, we have $\pi_q(n + s) - qb - c_e \geq 0$, which is equivalent to $b \leq \frac{\pi_q(n + s) - c_e}{q}$. Assume, by contradiction, that an incumbent does not get a licence. In particular, this means that the incumbent bids less than b on the above blocks, and that this incumbent has a payoff of $-\gamma(n + s) \leq 0$. Consider now a deviation where the incumbent bids $b + \varepsilon$ on the above blocks. With such a strategy, his payoff becomes $\pi_q(n + s - 1) - q(b + \varepsilon) - c_i \geq \pi_q(n + s - 1) - \pi_q(n + s) + c_e - c_i > 0 \geq -\gamma(n + s)$. Hence, the deviation is profitable, a contradiction to the assumption that we considered an equilibrium.

Proof of Conclusion 5: By the above conclusion, if an entrant gets a licence in equilibrium, then the four incumbents must also be licenced. Hence, the highest value[52] an entrant can ever achieve by being licenced is $\pi_3(5)$. Consider the following strategy profile: each entrant bids on three blocks up to $b_e = \frac{\pi_3(5) - c_e}{3}$ per block; each incumbent bids on three blocks up to $b_i = b_e + \varepsilon$ per block.[53] According to these strategies, entrants are not licenced, and get a payoff of zero. Bidding below b_e on one or more blocks cannot improve their payoff, while bidding $b > b_e$ on three blocks yields a payoff of $\pi_3(5) - 3b - c_e < \pi_3(5) - 3b_e - c_e = 0$ and bidding $b > b_e$ on two blocks yields a payoff of $\pi_2(5) - 2b - c_e < \pi_3(5) - 3b_e - c_e = 0$. Hence, the entrants' strategy cannot be improved upon. Consider now an incumbent. By bidding $b_i = b_e + \varepsilon$, he gets three blocks and is licenced. His payoff is given by $\pi_3(4) - 3b_i - c_i = \pi_3(4) - \pi_3(5) + c_e - c_i$

[52] Recall that $\pi_3(5) \geq \pi_2(5)$, and that $\pi_3(5) \geq \pi_3(6) \geq \pi_2(6)$.

[53] An equilibrium with the same physical outcome but with different payments exists if $\pi_3(4) - \pi_2(4) \geq \frac{\pi_2(5) - c_e}{2} \geq \frac{\pi_3(5) - c_e}{3}$. In this equilibrium, entrants bid only on two blocks.

$-3\varepsilon > 0 \geq -\gamma(4)$. It is clear that bidding higher on some blocks is not optimal. If the incumbent bids lower on two or more blocks, then he loses the licence, yielding a payoff of $-\gamma(4) \leq 0$, hence this cannot be optimal. If the incumbent bids lower on one block, then his payoff is given by $\pi_2(4) - 2b_i - c_i \leq \pi_3(4) - 3b_i - c_i$. We conclude that the described strategy is optimal for the incumbent, and that we have described an equilibrium.

Proof of Conclusion 6: By Conclusion 4, the six licenced firms must include the four incumbents. In an equilibrium with six licenced firms where the block price is b, entrants get a payoff of $\pi_2(6) - 2b - c_e$. Since this payoff must be non-negative we obtain $b \leq \frac{\pi_2(6) - c_e}{2}$. An incumbent's payoff is given by $\pi_2(6) - 2b - c_i$. Assume now that an incumbent deviates and bids $b + \varepsilon$ on one block. Then, there will be only five licenced firms, and this incumbent's payoff is given by $\pi_3(5) - 3b - \varepsilon - c_i$. For the outcome with six licenced firms to be an equilibrium, it is necessary that $\pi_3(5) - 3b - \varepsilon - c_i \leq \pi_2(6) - 2b - c_i$. This is equivalent to $\pi_3(5) - \pi_2(6) \leq b$. Because $b \leq \frac{\pi_2(6) - c_e}{2}$, we obtain the necessary condition $2(\pi_3(5) - \pi_2(6)) \leq \pi_2(6) - c_e$.

Proof of Conclusion 7: The only possible configuration with five licences is one where two firms acquire three blocks each, and three firms acquire two blocks each. By Conclusion 4 we obtain that two incumbents acquire three blocks each, two incumbents acquire two blocks each, and a new entrant acquires two blocks. Hence, there are two incumbents that can possibly improve their payoff by bidding on additional capacity. The proof proceeds then as in the previous conclusion.

REFERENCES

Ausubel, L. (1997). 'An efficient as cending-bid auction for multiple objects', Discussion Paper, University of Maryland.

Ausubel, L.M. and P. Cramton (1998). 'Demand reduction and inefficiency in multi-unit auctions', Working Paper, University of Maryland.

Ausubel, L. and P. Milgrom (2001). 'Ascending auctions with package bidding', Working Paper, Stanford University.

Binmore, K. and P. Klemperer (2002). 'The biggest auction ever', *The Economic Journal*, 112, C74–96.

Börgers, T. and J. Dustmann (2001). 'Strange bids: Bidding behavior in the United Kingdom's third generation spectrum auction', Discussion Paper, University College, London.

Caillaud, B. and P. Jehiel (1998). 'Collusion in auctions with externalities', *Rand Journal of Economics*, 29, 680–702.

Compte, O. and P. Jehiel (2000). 'On the virtues of the ascending price auction: new insights in the private value setting', mimeo, CERAS and UCL.

Cramton, P. (1997). 'The FCC spectrum auctions: An early assessment', *Journal of Economics and Management Strategy*, 6(3), 431–95.

Dasgupta, P. and E. Maskin (2000). 'Efficient auctions', *Quarterly Journal of Economics*, 115, 341–88.

Das Varma, G. (2000). 'Standard auctions with identity dependent Externalities', *RAND Journal of Economics*, 33, 689–708.

Demange, G., D. Gale and M. Sotomayor (1986). 'Multi-item auctions', *Journal of Political Economy*, 94(4), 863–72.

Deutsche Bank (2000). 'UMTS, the third generation game', Deutsche Bank Equity Research.

de Vries, S. and R. Vohra (2000). 'Combinatorial auctions: A survey', mimeo, Northwestern University.

Engelbrecht-Wiggans, R. and C. Kahn (1998). 'Multi-unit auctions with uniform prices', *Economic Theory*, 12, 227–58.

Ettinger, D. (2000). 'Toeholds and auctions', Discussion Paper, CERAS.

Ewerhart, C. and B. Moldovanu (2001). 'A stylized model for the German UMTS auction', Discussion Paper, University of Mannheim.

Gilbert, R. and D. Newbery (1982). 'Preemptive patenting and the persistence of monopoly', *American Economic Review*, 72, 514–26.

Grimm, V., F. Riedel and E. Wolfstetter (2001). 'The third generation (UMTS) spectrum auction in germany', Working Paper, Humboldt University, Berlin.

Gul, F. and E. Stacchetti (1999). 'Walrasion equilibrium with gross substitutes', *Journal of Economic Theory*, 87, 109–24.

Jehiel, P. and B. Moldovanu (1996). 'Strategic non-participation', *RAND Journal of Economics*, 27, 84–98.

— (1999). 'Resale markets and the assignment of property rights', *Review of Economic Studies*, 66, 971–91.

— (2000a). 'Auctions with downstream interaction among buyers', *RAND Journal of Economics*, 31(4), 768–91.

— (2000b). 'Licence auctions and market structure', Discussion Paper, University of Mannheim and University College London.

— (2000c). 'The European UMTS/IMT-2000 Licence Auctions', Working Paper, University of Mannheim.

— (2001a). 'Efficient design with interdependent values', *Econometrica*, 69, 1237–59.

— (2001b). 'A note on efficiency and revenue maximization in multi-object auctions', *Economics Bulletin*, 3(2), 1–5.

Jehiel, P., B. Moldovanu and E. Stacchetti (1996). 'How (not) to sell nuclear weapons', *American Economic Review*, 86, 814–29.

— (1999). 'Multidimensional mechanism design for auctions with externalities', *Journal of Economic Theory*, 85, 258–93.

Klemperer, P. (2000). 'What really matters in auction design', mimeo, Oxford University.

— (2001). 'How (not) to run auctions: The European 3G Telekom auctions', forthcoming in *European Economic Review*.

— (2002). 'Using and abusing economic theory', mimeo Oxford University.

Krishna, K. (1993). 'Auctions with endogenous valuations: The persistence of monopoly revisited', *American Economic Review*, 83, 147–60.

Maasland, E. and S. Onderstal (2001). 'Auctions with financial externalities', Discussion Paper, Tilburg University.

McAfee, R.P. and J. McMillan (1996). 'Analyzing the airwaves auction', *Journal of Economic Perspectives*, 10, 159–75.

McDaniel, D. and K. Neuhoff (2002). 'Use of long-term auctions for network investment', Working Paper WP 0213, University of Cambridge.

McMillan, J. (1994). 'Selling spectrum rights', *Journal of Economic Perspectives*, 8, 145–62.

Milgrom, P. (2000). 'Putting auction theory to work: The simultaneous ascending auction', *Journal of Political Economy*, 108, 245–72.

Milgrom, P. and R. Weber (1982). 'A theory of auctions and competitive bidding', *Econometrica*, 50, 1089–1122.

Moldovanu, B. and A. Sela (2001). 'Patent licensing to Bertrand competitors', forthcoming in *International Journal of Industrial Organization*.

Myerson, R.B. (1981). 'Optimal auction design', *Mathematics of Operations Research*, 6(1), 58–73.

Noussair, C. (1995). 'Equilibria in a multi-object uniform price sealed bid auction with multi-unit demands', *Economic Theory*, 5, 337–51.

Palfrey, T. (1983). 'Bundling decisions by a multiproduct monopolist with incomplete information', *Econometrica*, 51, 463–84.

Plott, C. (1997). 'Laboratory experimental testbeds: Application to the PCS auction', *Journal of Economics and Management Strategy*, 6, 605–38.

REG-TP (2000). 'Die Entscheidung der Präsidentenkammer vom 18.02.2000 über die Regeln für die Durchführung des Versteigerungsverfahrens zur Vergabe von Lizenzen für UMTS/IMT-2000; Mobilkommunication der dritten Generation', Aktenzeichen: BK-1b-98/005-2.

UBS Warburg (2000). '3G Hysteria! Not everyone's idea of fun and games', mimeo, UBS Global equity Research.

van Damme, E. (2000). 'The Dutch UMTS auction in retrospect', cpb Report 2001/2.

WestLB Panmure (2000). 'UMTS. The countdown has begun', mimeo, WestLB Panmure, Pan European Equity.

Wilson, R. (1979). 'Auctions of shares', *Quarterly Journal of Economics*, 94, 675–89.