The European UMTS/IMT-2000 License Auctions

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Abstract

We survey the recent European UMTS license auctions and compare their outcomes with the predictions of a simple model that emphasizes future market structure as a main determinant of valuations for licenses. Since the main goal of most spectrum allocation procedures is economic efficiency, and since consumers (who are affected by the ensuing market structure) do not participate at the auction stage, good designs must alleviate the asymmetry among incumbents and potential entrants by actively encouraging entry.

1. Introduction

Europe has taken the global lead in the issuance of third generation (3G) licenses for mobile telecommunications according to the UMTS/IMT 2000 family of standards. First generation networks offered simple analogue voice telephony; current systems (2G according to the GSM standard) added some data services like fax and e-mail; Besides increased encoding efficiency (up to five times), 3G networks should, in theory, be capable of providing transmission rates up to 2 Megabits per second, and thus the prospect of high-resolution video, multimedia, mobile office, virtual banking, and many other on-line services.

The European licensing activity is summarized in Table 1. Several countries (e.g., Finland, Spain, Norway, Sweden, France) have opted for so called "beauty contests" in which licenses are allocated on the basis of a bureaucratic procedure where several criteria (such as technical expertise, financial viability, network coverage, etc...) are evaluated. These processes are not transparent, are prone to intense lobying and political intervention, and it is difficult to assess whether they fulfill some pre-specified goals.

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Other countries (e.g., UK, Holland, Germany, Switzerland, Italy, Austria) decided to allocate licenses via an auction procedure[1]. After observing the auction revenue obtained in places like the UK and Germany, even countries that previously opted for beauty contests changed the rules of the game. For example, Spain considers selling an additional license through auction (the official licensing procedure has been completed long ago), and France raised the licensing fee to a staggering Euro 5 Bn per license. But, contrary, to most accounts in the media, revenue maximization is not, and should not, be the main goal of spectrum auctions.

1.1. The Main Goal: Economic Efficiency

Besides merely allocating spectrum, beauty contests or auctions actively shape future market structure in the telecommunications industry. The main goal of most such allocation procedures is economic efficiency, which, correctly interpreted, means the maximization of the (possibly weighted) sum of consumer and producer surplus. This maximization exercise must necessarily consider several alternative market scenarios. In particular, it is important to realize that future firm profits and consumer rent will be determined by the number of licensed firms. A secondary goal (invariably less advertised in official documents, but playing an increased role in practice) is raising revenue for the government[2].

A serious hurdle on the way to economic efficiency[3] is due to the obvious fact that consumers do not directly participate at the spectrum auctions or beauty contests. Moreover, an ex-ante measurement of expected consumers' surplus in various market constellations is very difficult. Therefore, consumer surplus does not naturally play a role, unless special provisions are made in a careful design. How should these provisions look like? Since standard oligopoly models predict that in reasonable ranges both consumers' surplus and overall efficiency increase with increased competition among firms, the creation of sufficient market competition becomes a proxy goal that can be successfully implemented by license and capacity allocation schemes. This means that market entry should be actively encouraged as long as it is economically viable. It is obvious that this encouragement must come at the licensing stage since afterward entry is practically impossible (due to spectrum scarcity, network effects, regulatory constraints, etc...).

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

[2] The popular media tends to focus on revenue. Moreover, it seems that the UK auction has opened the appetite of several European governments.

[3] Another, more technical difficulty is presented by the fact that, in complex situations fitting well some spectrum auction environments, multi-unit efficient allocation procedures simply do not exist and second-best mechanisms are not yet known (see Jehiel and Moldovanu, 1998).

1.2. Incumbents and Entrants

Potential new entrants (i.e., firms that do not already operate a GSM network in the respective country) face two major difficulties: 1) The fixed cost of setting up the infrastructure required for 3G services is very large[4]. In contrast, some of the 2G incumbents' fixed costs are already sunk, since they can use significant parts of their already existing facilities[5] (e.g., base station sites). 2) A common prediction is that per-firm industry profit in oligopoly decreases in the number of active firms[6]. Hence, besides expected profits from offering 3G services, incumbents are also driven by entry pre-emption motives[7] (e.g., the need to avoid further losses relative to the status quo) which translate into increased willingness to pay for licenses and capacity. Moreover, the advent of 3G networks with more active firms will cannibalize also some of the incumbents' profits in the 2G area since future 3G operators are usually allowed to offer also 2G services based on the GSM standard.

For any bidder at a license auction, the "pure" economic value of a license with a fixed capacity is given by the value of expected profits from operating the license. This value increases if the license is endowed with more capacity, and decreases if more firms are licensed.

An entrant's valuation for a license with a fixed capacity is obtained by subtracting from the expected profit (which depends on the expected number of licensed firms) the fixed cost required to build a network.

Besides the need to subtract lower infrastructure costs, an incumbent's valuation for a license with a fixed capacity is obtained by adding to the expected profit (which depends on the expected number of licensed firms) the profit that will be lost relative to status quo if that incumbent does not get a 3G license. Tables 2 and 3 illustrate how a major investment bank estimated license values as a function of the various possible market constellations. While the numbers may or may not be correct, it is obvious that market structure considerations and the incumbent/entrant asymmetry played a major role in that bank's estimates.

Assuming that firms are otherwise comparable (in terms of costs, know-how, managerial skill, financial strength, etc...), we obtain that, in any feasible market constellation, incumbents place higher values on licenses than entrants do. Hence, incumbents are willing to bid higher than entrants, and we should expect that all

[4] The estimates are of the order of several billions of Euros for large countries. UMTS operates at higher frequencies, which means that more cells and basis stations are needed than in GSM networks.

[5] Some incumbents also enjoy large customer bases ans strong brand names.

[6] For the effects of such a specification in license auctions with symmetric firms, see Kamien (1992), Katz and Shapiro (1986), Kamien and Tauman (1986), Rodriguez (1998). Jehiel and Moldovanu (1996a) allow for asymmetry among firms and explicitly consider incumbents and entrants.

[7] These and similar effects are well documented and understood, in particular in the area of innovation - see for example Gilbert and Newberry (1982), Krishna (1993, 1999). In the context of spectrum license auctions, see also Jehiel and Moldovanu (2000).

GSM incumbents get licenses if at least one new entrant is licensed.

A consequence of the above conditions is that the playing field among incumbents and potential new entrants is far from being level, even if the firms are otherwise (e.g., technically, managerially, financially) alike. Entering the market by directly overbidding GSM incumbents seems quite difficult unless new entrants are much more efficient and therefore expect higher profits, or incumbents have tighter budget constraints, etc...If potential new entrants perceive this disadvantage[8], they will either not bother to bid at all, or they will try to form consortia with incumbents. Both types of behavior will have an adverse effect on competitiveness and revenue.

It is of course conceivable that special circumstances lead to an entrant having a higher value than an incumbent. For example, a particular country license may be the "last piece in the puzzle" for a global firm which consequently may be willing to pay more than a small incumbent with only local interests. But such features are hard to predict a-priori, and are subject to constant change since firms form and break alliances, change business plans, etc... In our view considerations based on such transitory features should not play a major role in auction design.

The main question remains how to use the auction design in order to alleviate the incumbent-entrant asymmetry and to encourage entry.

1.3. Entry Considerations in Practice

1.3.1. The Number of Licenses

The most important variable for controlling entry (and, in our view, one of the most important ingredient for auction design) is the number of licenses. The number of new 3G licenses was a hotly debated issue during the UK auction design stage. In order to achieve economic efficiency the eventual UK design actively tried to level the playing field among incumbents (there are 4 GSM incumbents) and new entrants. Its main feature was reserving the largest license for a new entrant. On that license only entrants were allowed to bid.

Note than an initial plan called for an ascending auction of 4 licenses[9], complemented by a sealed-bid stage to be conducted when only 5 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 Klemperer, 2000). After many subsequent deliberations about the "right" number of licenses, the designers fixed it to be 5, one more than the number of incumbents[10].

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

[9]We have vigorously argued against this proposal, for reasons completely analogous to those that guided us in our critique of the German design.

[10]In this transition, the final sealed-bid stage has been abandoned as well.

In contrast to the UK, the Dutch regulatory agency did not recognize that a directed intervention in order to help new entrants is necessary. It organized an auction for 5 licenses, where 5 was also the number of GSM incumbents[11].

The German regulatory agency also did not recognize that a directed intervention in order to help new entrants is necessary[12] or fair towards established firms. The German design[13] is quite flexible, and it allows both for an endogenous number of licenses and for endogenous capacity endowments (see description below). 2 new firms (one more than in the UK) can enter the market, but, by acquiring more than the minimal capacity needed in order to be licensed, the incumbents can completely preempt entry[14]. An earlier design which called for 5 licenses has been abandoned in favor of the present one, because the flexible design was thought to offer "a fair, undiscriminating, and efficient market solution to the problem of finding the optimal number of licenses". Moreover, general principles of competition policy "require to allow the highest possible number of firms to enter the market".

Related to the number of licenses, the Italian design had a rather naive feature: It stipulated that, after the bidders qualify for the auction, the number of licenses can be reduced to ensure that there are more licenses than bidders. Not surprisingly, the number of bidders that were actually willing to bid was equal to the a-priori maximal number of licenses plus one so that no reduction occured. But one firm very quickly dropped out of the auction (see below for a description of the outcome). That kind of naivete was surpassed by a twist used in a Turkish sequential design where the reserve price for a second license was set to be equal to the selling price of the first license[15]. Consequently, the winner of the first license did very high, presumably more than expected duopoly profits. Since no second firm could have bid so high for the second license, that license was not sold, leaving the first winner with a monopoly !

Considerations about entry are not confined to the realm of auction design. Spectrum allocations by other means must also give an adequate answer to the above problems. Indeed, it is interesting to note that most of the countries which

[11] Of course, the Netherlands is a relatively small country, and it may be argued that 5 firms are sufficient. But then it is not clear to us why an auction was considered appropriate.

[12] REG-TP has offered extensive explanations (more than 100 pages) for the chosen licensing procedure. Conceptual errors are common. For example, in the official German document explaining the auction design (AK: BK-1b-98/005-2, page 17) we are told that a simultaneous ascending auction complemented by various activity rules is used in order to reduce the "winner's curse" (note that this phenomenon can occur only if the bidders' valuations have some "common value" components). In the same paragraph, we are also told that in the present auction it is enough for bidders to bid up to their valuations, and that they need not spend resources to get informed about competitors (note that this strategy is optimal in some auctions **without** common value components, with unit demand, and without allocative externalities; it is completely meaningless here...).

[13] That design has been also used in Austria. See below.

[14] We harshly criticised this feature in a previous working paper called "A Critique of the Planned Rules for the German UMTS/IMT- 2000 License Auction".

[15] For this and other stories, see Binmore (2000).

opted for beauty contests adhered to a simple formula that made entry inevitable:

$$\text{Number of 3G Licenses} = \text{Number of GSM Incumbents} + 1$$

1.3.2. Facilitating entry by reducing infrastructure costs

There are several other feature, not directly pertaining to the auction rules, that may influence the probability of successful entry through auctions. The adoption of all or some of the following rules has the effect of decreasing the infrastructure costs (including financing costs), with a stronger relative effect on entrants. They can play an important role in leveling the field between entrants and incumbents. Italy, for example, wisely adopted all three measures described below.

1. Mandatory roaming. This stipulation requires GSM incumbents to grant an entrant access (for an appropriate fee) to their networks while the entrant builds its own infrastructure. This means that a new entrant can immediately start to offer 2G services and generate a positive cash flow for the several years it takes to build a new network. The UK design originally included this feature, but it was overturned following a suit brought by an incumbent (DT's subsidiary OneToOne). A "voluntary" agreement between the government and two other incumbents will now guarantee free roaming. In Germany the incumbents complained that a free roaming stipulation infringes on their existing rights, as defined by the terms of their GSM licenses, and the idea was abandoned. The regulatory agency argued that roaming agreements can and will be achieved by bilateral bargaining

2. License fee payment by installments. Another way to ease the financial constraints is to parse the license fee over several years. While this rule benefits all firms, it is particularly important for new entrants whose cash flow is going to be negative in the first years, due to the large infrastructure investment. UK adopted such a plan, but the required interest rate was so high that firms chose not to use this opportunity. In contrast, Germany required full payment just 10 days after the auction. As it became clear that the fees are going to be enormous, adverse reactions on the share prices and bond ratings were triggered. These reactions were partly responsible for the timing of the auction's end (see details below). At the moment, at least one new entrant is said to be in serious financial difficulties and its shae price has plummeted.

3. Mandatory site sharing. This stipulation requires GSM incumbents to grant access to their antennae and relay installations, so that several firms can use the same facility. Note that 3G networks will require a denser cell structure than existing 2G networks. Moreover, it is increasingly difficult to obtain authorization for new sites, due to planning and environmental restrictions. Dealing with this issue is thought to constitute a sizable share

of the infrastructure costs. Hence, mandatory site sharing can considerably reduce these costs. Not surprisingly, incumbents have argued that, due to technical constraints, site sharing is not feasible on a large scale.

The rest of the paper is organized as follows: In Section 2 we describe the main rules of several European license auctions. In Section 3 we sketch a simple auction model. We differentiate among several cases, depending on whether the number of licenses was fixed or endogenous. In Section 4 we compare the model's equilibria with the observed auction outcomes. In Section 5 we discuss several issues connected to the possibility of collusion. Concluding comments are gathered in Section 6. Section 8 displays various tables that summarize the empirical evidence.

2. The Main Rules of Several European Auctions

2.1. The UK Auction

The chosen design revolves around a simultaneous multiple-round ascending auction, augmented by various activity rules that control the speed of the auction and limit to some extent gaming behavior. After each round all bids were revealed to the bidders. The simultaneous approach and the concept of activity rules have been introduced and widely employed by the US Federal Communication Commission[16]. In our view, the most important decision concerned the number of auctioned licenses, which was finally fixed to be 5, one more than the number of GSM incumbents. Moreover, only new entrants were allowed to bid on license A, which was also endowed with the highest capacity, 2×15 MHz (paired spectrum) + 1×5 MHz (unpaired spectrum). Bidding on licenses B,C,D and E was open to all qualified bidders. License B was endowed with 2×15 MHz , while licenses C, D, E were endowed with $2 \times 10 + 1 \times 5$ MHz each. Hence, both the number of licenses and their capacity endowments were fixed in advance by the regulator.

2.2. The Dutch Auction

There were 5 licenses and 5 GSM incumbents. Licenses A and B had a capacity of 2×15 MHz, licenses C,D,E had a capacity of 2×10 MHz. The auction was simultaneous and ascending and in each round a bidder could bid on at most one license. 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. A minimum increment of 10% of the current price was used throughout the auction. The information revealed at each stage consisted of: number of bids on each license, number of highest bids, highest current bidders and their bids. Finally, there was a reserve price of about Euro 50 million for

[16] See for example McMillan (1994), McAffe and McMillan (1996) and Milgrom (1997)

each license, but this price could be reduced after a stage in which no bids were made on that license.

2.3. The German and Austrian Auctions

The rather complex design involved two consecutive auctions. The first auction allocates licenses[17] together with so called "duplex" or "paired" spectrum frequencies . The second auction allocates paired spectrum that has not been sold at the first auction, together with additional "unpaired" spectrum. Both auctions are of the "simultaneous multiple-round ascending" type.

The License Auction Bidders do not directly submit bids for licenses. Instead, the auctioned objects are 12 blocks[18] of paired spectrum. Each block consists of 2×5 Mhz.

The crucial design ingredient is as follows: A bidder obtains a license only if he acquires at least two blocks, but a bidder is allowed to acquire (at most) three blocks. As a consequence, both the number of licensed firms and the capacity endowments are endogenous. The number of licensed firms can, in principle, vary between 0 and 6. Note that if all blocks are sold there will be no less than 4 licenses (which equals the number of GSM incumbents in both Germany and Austria)

Each block has a reserve price of DM 100 Million in Germany and Euro 50 Million in Austria. The design was complemented by various activity rules[19]. Most importantly, at each round a bidder must bid on at least two blocks (although the blocks were abstract and identical, bids carried name tags). Bidding on only two blocks at round t precludes bidding on three blocks at all rounds $t' > t$.

A block may fail to be sold either because there were no bids for that block above the reserve price, or because the bidder who submitted the highest bid on that particular block ultimately fails to acquire two blocks (and hence fails to be licensed), in which case he is not required to make a payment[20].

The Auction for Additional Capacity The purpose of the second auction is to allocate additional capacity among the bidders that were licensed at the first auction. This means that only those bidders that previously acquired at least two paired blocks of 2×5 MHz are allowed to participate.

[17] Licenses are awarded for a period of 20 years, and no resales are allowed.

[18] Blocks are "abstract", i.e., the exact location of each block in the spectrum will be determined ex-post, to ensure that a bidder gets adjacent blocks.

[19] For example, in each round of the German auction, bids can be increased only by a pre-announced minimum increment which is a multiple of DM 100.000.

[20] Since bidders are, at each round, required to seriously bid on at least two blocks, it is not possible to bid high on a unique bid just in order to make others pay more.

Besides unsold paired blocks from the first auction, the second auction will allocate additional 5 unpaired blocks of 1×5 MHz each[21]. Bidders can acquire any number of unpaired blocks, but are not allowed to acquire more than 1 paired block. Each unpaired block had a reserve price of DM 50 Million in Germany, and Euro 25 Million in Austria.

2.4. The Italian Auction

There were a maximum of 5 identical licenses[22] with a capacity of $2 \times 10 + 1 \times 5$ MHz. An interesting rule stipulated that, in case that there are only 5 or less bidders at the auction, the number of licenses can be reduced to be one less than the number of bidders.

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 license). Each winner was supposed to pay his own bid (and not, for example, the highest losing bid). The reserve price was about Euro 2 billion per license.

3. A Simple Model

We use the following simple models in order to make precise several verbal arguments made in the Introduction. Moreover, we believe that the model helps to understand the concepts that are necessary for conducting an informed discussion. Its main feature is the fact that valuations for licenses are endogenous, and depend on market structure. This aspect seems to be very well understood by firms and analysts. For example, a major investment bank[23], estimated per license values of Euro 14.75 Bn, 15.88 Bn and 17.6 Bn for a German symmetric market with 6, 5, or 4 firms, respectively. Such a feature (which abstractly translates in the presence of allocative externalities) has been only recently introduced in the theoretical auction literature[24] (see Jehiel and Moldovanu, 1996a, 1996b, 1998, 2000a, 2000b).

[21] Only 4 of the unpaired blocks are abstract, while the fifth one is isolated, and may be used only under additional constraints. Hence, if 5 firms become licensed at the first auction, at least one of them must get capacity of somewhat reduced quality at the second auction. If the first auction produces 6 licensed bidders, then at least one of them will not be able to acquire any additional capacity at the second auction.

[22] Licenses were awarded for a duration of 15 years.

[23] See "UMTS. The countdown has begun" by WestLB Panmure, 2000.

[24] An excellent recent survey of the "traditional" auction literature - where values are either exogenous or only subject to informational externalities- is offered by Klemperer (1999).

3.1. A pre-determined number of licenses (UK , Holland, Italy[25])

The bidders at the auction are the $n \geq 2$ special firms called "incumbents" and $m \geq 2$ firms called "entrants"[26]. A fixed number $k \geq n$ of new 3G licenses are auctioned[27]. 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[28].

Bidders are characterized by values attached to feasible auction outcomes. These **endogenous** values reflect the expected profits in various feasible market constellations. 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.

Suppose that $s \leq k$ entrants acquire a new license. 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 license. This profit is a decreasing function of the total number of licensed firms in the market. 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 license[29]. The positive function γ is also decreasing in its argument. The expected profit of a potential entrant that does not get licensed is zero.

Finally, we denote by c_i and by c_e the fixed costs that must be born by an incumbent and by an entrant, respectively, in order to build a viable 3G network. These costs are deemed to be significant in relation to the above values, and we also make the realistic assumption that $c_e - c_i > \varepsilon$.

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

3.1.1. Analysis

In our present framework, simultaneous ascending auctions have, for each set of parameters, many equilibria, resulting in different allocations and payoffs. Moreover, the equilibrium number of licensed firms may vary with the parameters.

[25] As mentioned above, the Italian design had a predetermined number of licenses once it became clear how many bidders qualified for the auction.

[26] For example, there were 9 entrants bidding in the UK auction.

[27] In all planned or completed UMTS auctions the number of licenses was at least as large as the number of GSM incumbents. For an analysis of the "war of attrition" phenomenon occuring when this assumption is not fulfilled, see Jehiel and Moldovanu (2000).

[28] 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.

[29] For example, this includes profits that an incumbent expects to loose in the 2G market (relative to the status-quo), or losses felt by the management of a potentially shrinking firm, etc...

Besides various technical details associated with the simultaneous ascending auction (which play no role for our argument[30]), the multiplicity is also caused by the fact that valuations are endogenous and depend on expectations about the final number of licensed firms.

We "ignore" below the reserve prices, i.e., we assume that the relevant equilibrium bids are all above the reserve price. Moreover, we consider below only equilibria where identical objects (licenses or capacity blocks) sell for the same price (modulo minimum bid increments). In fact, 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.

Proposition 3.1. *Consider any equilibrium where at least one entrant acquires a license (with probability 1). In this equilibrium, each of the incumbents must acquire a license.*

Proof. Consider an equilibrium where $s \geq 1$ new entrants are licensed, and consider a new entrant who payed $p \geq 0$ for its license (call this license A). Since the 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 license. In particular, this means that this incumbent bids less than p on license 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 license. 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. ■

Remark 1. *Roughly speaking, the above Proposition shows that incumbents have higher valuations than new entrants (recall that valuations are endogenous here). There are three reasons why this is so. First, irrespective of the market structure configuration, the fixed cost c_i of incumbent is higher than that of entrants c_e. Second, incumbents are ready to pay an extra $\gamma(n+s)$ as compared with entrants because of the synergy between 2G and 3G licenses. Third, - since incumbents are already present in the market - the acquisition of a 3G license by an incumbent is less damaging to the per-firm profits than the acquisition by an entrant. This is reflected by the fact that $\pi(n+s-1) - \pi(n+s) > 0$.*

Remark 2. *In view of the remark above, we implicitly use below the only tie-breaking rule that is consistent with more general formulations (where valuations are continuously distributed and strictly higher valuations lead to strictly higher bids): a new entrant cannot win a license if there is an incumbent who bids at least as high as the entrant on that block.*

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

Proposition 3.2. *Assume that the number of new licenses equals the number of incumbents, i.e., $k = n$, and that $\pi(n+1) - c_e \geq 0$ .The following strategies define an equilibrium: each entrant bids $\pi(n+1) - c_e$ and each incumbent bids $\pi(n+1) - c_e + \varepsilon$. In this equilibrium all incumbents get licensed, there is no additional entry, and revenue is approximately given by $n\pi(n+1)$.*

Proof. 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 license to an entrant, yielding a payoff of $-\gamma(n+1) \leq 0$. 2) Given that an entrant expects that all other licenses go to incumbents, the value of a license to an entrant is $\pi(n+1) - c_e$. ■

Proposition 3.3. *Assume that the number of new licenses is higher than the number of incumbents, i.e., $k > n$, and that $\pi(k) - c_e \geq 0$. The following strategies define an equilibrium: each entrant bids $\pi(k) - c_e$ and each incumbent bids $\pi(k) - c_e + \varepsilon$. In this equilibrium all incumbents get licensed, $k - n$ entrants also get licensed and revenue is approximately given by $k\pi(k)$.*

Proof. If the above strategies are played, entrants (whether licensed 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 license to an entrant, yielding a payoff of $-\gamma(k+1) \leq 0$. 2) Given that an entrant expects that n out of k licenses go to incumbents, the value of a license to an entrant is $\pi(k) - c_e$. ■

3.2. An endogenous number of licenses (Germany, Austria)

The bidders at the auction are the $n = 4$ special firms called "incumbents" and $m \geq 2$ firms called "entrants". 12 identical blocks are auctioned according to the rules detailed in Section 2.3[31]..

If s new entrants acquire 3G licenses, 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 licensed firms in the market. We assume that π_q is decreasing in n and increasing in k. The rest of the definitions, notation and assumptions is as above.

3.2.1. Analysis

We first prove a Proposition that identifies the advantage enjoyed by incumbents.

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

Proposition 3.4. *Consider any equilibrium where at least one new entrant acquires $q \geq 2$ blocks (and thus it is licensed). In this equilibrium, each of the 4 incumbents acquires at least q blocks (and thus all 4 incumbents must also be licensed).*

Proof. Consider an equilibrium where $n+s$ firms are licensed, 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 license. 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[32]. 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. ■

There are three main outcomes, differing by the number of licensed firms. The next three results determine the conditions on the parameters that are necessary in order to sustain each outcome. The conditions relate the firms' valuations in various market constellations.

Proposition 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. If $\pi_3(4) - \pi_2(4) \geq \frac{\pi_3(5)-c_e}{3} \geq \frac{\pi_2(5)-c_e}{2}$ then this profile constitutes an equilibrium*[33]. *The licensed firms are the 4 incumbents. The revenue in this equilibrium, approximately $4(\pi_3(5) - c_e)$, is the highest possible among all symmetric equilibria with 4 licensed firms.*

Proof. By the above Proposition, if an entrant gets a license in equilibrium, then the 4 incumbents must also be licensed. Hence, the highest value[34] an entrant can ever achieve by being licensed is $\pi_3(5)$. According to the above described bidding strategies, entrants are not licensed, 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 $\pi_2(5) - 2b - c_e \leq \pi_3(5) - 3b - c_e < \pi_3(5) - 3b_e - c_e = 0$. 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 licensed. His payoff is given by $\pi_3(4) - 3b_i - c_i = \pi_3(4) - \pi_3(5) + c_e - c_i - 3\varepsilon > 0 \geq -\gamma(4)$. It is clear that bidding higher on some blocks is not optimal. If the incumbent

[32] In an equilibrium where not all blocks sell for the same price, the proof is modified by letting the incumbent mimic the entrant.

[33] An equilibrium with the same physical outcome (4 licensed incumbents) but different payments exists also 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.

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

bids lower on two or more blocks, then he looses the license, 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 ■

Proposition 3.6. *A necessary condition for the existence of an equilibrium with 6 licensed firms is given by* $\pi_3(5) \leq \frac{3\pi_2(6)-c_e}{2}$.

Proof. By Proposition 3.4, the 6 licensed firms must include the 4 incumbents. In an equilibrium with 6 licensed 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 licensed firms, and this incumbent's payoff is given by $\pi_3(5) - 3b - \varepsilon - c_i$. For the outcome with 6 licensed 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 $\pi_3(5) \leq \pi_2(6) + b$. Because $b \leq \frac{\pi_2(6)-c_e}{2}$, we obtain the necessary condition $\pi_3(5) \leq \frac{3\pi_2(6)-c_e}{2}$. ■

Proposition 3.7. *A necessary condition for the existence of an equilibrium with 5 licensed firms is given by* $\pi_3(4) \leq \frac{3\pi_2(5)-c_e}{2}$.

Proof. The only possible configuration with 5 licenses is one where 2 firms acquire 3 blocks each, and 3 firms acquire 2 blocks each. By Proposition 3.4 we obtain that 2 incumbents acquire 3 blocks each, 2 incumbents acquire 2 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 follows exactly as in the previous Proposition. ■

4. Comparison between Auctions' Outcomes and Models' Predictions

4.1. UK Outcome

There were 13 participating bidders, and 150 rounds of bidding. The results are summarized in Tables 4 and 5. 4 licenses were acquired by the 4 GSM incumbents (with the largest unreserved license going to Vodafone), while the reserved license A was acquired by an entrant, TIW. Total revenue was £22.5 billion. The identical licenses C, D, and E sold for the same price (slightly more than £4 billion), while licenses A and B were more expensive (they were endowed with more capacity). In spite of the high prices, and in spite of "expressions of shock" uttered by various firms, analysts do not believe that firms have overpaid, i.e., the discounted value of expected profits minus infrastructure costs is likely to be higher than the license prices (see table 1 for the estimates of a major investment bank). The outcome is the one predicted by Proposition 3.3, where the number of licenses was higher than the number of incumbents, and where all incumbents get licensed. 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. Higher valuations for incumbents constituted indeed the driving force behind our theoretical results.

4.2. Dutch Outcome

There were 6 bidders (5 incumbents, one entrant). The results are summarized in Table 6. The five licenses were acquired by the five GSM incumbents (with the large licenses going to KPN and to Vodafone's subsidiary, Libertel). Total revenue was a relatively low 2.7 billion Euro. These features agree well with the prediction of Proposition 3.2, where the number of licenses equals the number of incumbents, and where no entrants are licensed. Several interesting things happened during the auction: In the first stages of the auction all bidders used pass-cards, thus bringing the reserve prices (with the exception of one license) to zero ! This considerably prolonged the auction. Also, the only participating new entrant, Versatel, stepped out very early claiming that it was threatened not to drive prices up by an incumbent (BT's subsidiary, Telfort). This disappointing, but predictable, outcome is now the subject of a parliamentary inquiry.

4.3. German Outcome

The outcome is summarized in Tables 7 and 8. The German auction was probably the most dramatic one since the government risked a highly concentrated market by explicitly exploiting preemptive motives (probably for the sake of increased revenue). Luckily for the government, the outcome produced both high revenue and two new entries[35].

There were only 7 bidders (including 4 GSM incumbents), after 6 other qualified bidders ultimately withdrew from the auction. The auction's first stage lasted for 3 weeks and 173 rounds of bidding, and resulted in 6 licenses being awarded. The licensed firms were the 4 incumbents and two new entrants (one of them already operating as service provider). Each licensed firm acquired 2 blocks of paired spectrum at the main license auction (recall the complex design described above), and each license cost approximately Euro 8.4 Bn (or Euro 4.2 Bn per block). The most interesting thing occurred after one of the potential entrants, Debitel, left the auction after 125 rounds and after the price level reached Euro 2.5 Bn per block. Since 6 firms were left bidding for a maximum of 6 licenses, 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, after intense pressure from

[35] Klemperer (2000) joins our opinion that the successful outcome (from the point of view of the government) was due to luck rather than good design.

stock markets and bond rating agencies[36], bidding for more capacity stopped in round 173. Compared to round 125, there was **no change** in the physical allocation, but firms where, collectively, **Euro 20 Bn poorer**!

Can this bizarre outcome be explained ? Note that a design that allows for a flexible number of licenses and a flexible capacity endowment for these licenses completely endogenizes the bidders' valuations and opens the door to complex gaming behavior during an ascending auction. The specific capacity limitation rules implied that in any possible auction outcome which includes entry (with 5 or 6 licensed firms) there is at least one new firm (this must be an entrant by the result of Proposition 3.4) that has acquired exactly the minimum mandated two blocks. If this firm looses one block, then it looses the entire license. Thus, besides getting "pure" economic value 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 license to a new entrant, thus avoiding a foreseeable decrease in expected profits caused by additional entry.

We believe that the main reason why prices were so high[37] is due to the willingness of the incumbents (in particular the two large ones) to preempt entry. But the incumbents' attempt failed, as there were eventually 6 licensees (see Proposition 3.6 for the conditions that are necessary to sustain such an outcome while assuming equilibrium behavior; we cannot assess whether the bizarre outcome was indeed consistent with equilibrium) There are several potential explanations for this failure. First, as mentioned above there was an intense pressure from stock markets (and it is not clear that the stock market pressure could have been easily anticipated). Second, since there were only two financially strong incumbents, and 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 avoiding a second entry was somewhat reduced (even though the two big incumbents were apparently ready to pay a lot to have only five licensees). Third, it is plausible that France Telecom's insistence to enter the German market was (at least partly) driven by the wish to revenge the previous "treason" by its former partner, Deutsche Telekom.

Another intriguing explanation for the level of prices arises by noting that DT is still majority owned by the German government. Hence, by driving up prices, DT clearly served the interest its major shareholder who happened to be the auctioneer (while the price it paid itself can be partly seen as a transfer from one government pocket to another)[38].

In the second stage 5 firms (3 incumbents and 2 entrants) each acquired an additional block of unpaired spectrum. There was no serious bidding in which firms tried to acquire more capacity - note that the preemptive motive was greatly re-

[36] Most bond ratings for the involved firms were subsequently downgraded from AA to A.

[37] Note that prices per head were still lower than in the UK .

[38] Several winning firms expressed their anger about that. A lawsuit was brought by one of the small incumbents, but it was not further pursued.

duced in that stage since the number of licenses was already determined. It seems that the enormous price paid at the first stage did not allow further flexibility (in particular, the smallest incumbent Viag Interkom was so budget constrained that it could not afford serious bidding at all).

4.4. Austrian Outcome

In Austria there were exactly 6 bidders (4 of them GSM incumbents) for a maximum of 6 licenses. Hence, in principle, the license auction could have ended immediately, at the reserve price (Euro 50 mil. per license). Nevertheless, a phenomenon similar to the German one occurred. The license auction continued for another 16 rounds, before stopping with...6 licensed firms, each paying Euro 120 mil. per license (see Table 9). Hence, about Euro 420 mil. have been again spent for "nothing" while firms tried to buy more capacity and reduce the number of licenses.

4.5. Italian Outcome

There were 6 bidders, 4 incumbents and 2 new entrants. Hence, according to the rules, the number of licenses was not reduced and remained fixed at 5, and at least was one new entry was inevitable. The auction ended after 11 rounds, after Blu, the smallest and weakest incumbent, dropped out. The remaining 5 firms paid about Euro 2.4 billion per license (see Table 10). Apparently, 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 of and other firms of manipulations[39]. Threats to cancel the auction while forfeiting the deposits (which were about as high as the final prices) were aired. Finally, the auction's outcome has been authorized. It is possible that, besides Blu's management and organization problems, the generous stipulations made for entrants (see Subsection 1.3.2) contributed to the auction's outcome.

5. Collusion

All above considerations were based on a behavioral model which assumes that bidders do not collude. Of course explicit collusion during the auction is forbidden by the auction rules in all countries, and usually severe steps are taken to ensure that bidders cannot directly communicate during the auction. But "tacit collusion" remains a major issue. We briefly discuss here several issues that also relate to the incumbent -entant asymmetry. For other themes related to collusion see also Klemperer (2000)

[39] The idea was that Blu has been possibly "asked" to take part in the auction by other firms, thus keeping the number of licenses at 5.

Jehiel and Moldovanu (2000) argue that the simultaneous ascending auction (through its dynamic, iterative structure) is well suited for incumbents who wish to coordinate in order to prevent entry[40] (without the need of external monetary transfers). Well designed activity rules can partly alleviate this problem, but cannot completely solve it.

To illustrate how coordination through signaling of intentions (which is legitimate given a design that makes it possible) might work, it is instructive to recall the result of the October 1999 German auction of extra capacity for the GSM-1800 standard. The auction covered 10 blocks of paired spectrum. Nine blocks were identical, each consisting of 2×1 MHz, while the tenth block consisted of 2×1.4 MHz. Reasonably, only the 4 GSM incumbents were allowed to bid. Besides a clear need for extra capacity in congested areas, it is possible that the large players (DT's subsidiary T-Mobil, and Vodafone's subsidiary Mannesmann) were driven by a preemptive motive. The auction was conducted in a simultaneous ascending format and the rules did not contain any limitation about the capacity that can be acquired by any one firm. The auction proceeded as follows: After the first round, the high bidder on all 10 blocks was Mannesmann, which offered DM 36.360.000 for each of blocks 1-5, DM 40.000.000 for each of the blocks 6-9 (which, recall, are identical to blocks 1-5), and DM 56.000.000 for the larger block 10. In the second round, T-Mobil bid[41] DM 40.010.000 on blocks 1-5, and the auction closed. Hence, each of the two larger firms got 5 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*, October 29, 1999, p.13).

Jehiel and Moldovanu (2000) also analyze how the possibility of tacit collusion (requiring no explicit agreement) is affected by other features of the auction format, most importantly the relation between the number of incumbents and the number of licenses. An insight derived there is that, from the point of view of incumbents, sustaining the best collusive outcome as a Nash equilibrium in the auction is more difficult (and may fail) if there is no focal, symmetric method which allows the incumbents to share the preemption 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 [42]. In the German 3G design there was an additional, countervailing, effect since buying more capacity (which could preempt entry) had also a pure economic value. Towards the end of the auction there was clear signaling activity among the two large incumbents who try to sort out whether to continue bidding in order to reduce the number of en-

[40] They also discuss the possibility of explicit collusion which requires external monetary transfers. For this, see also Caillaud and Jehiel (1998).

[41] Minimum increments had to be 10% of the last high bid.

[42] For example, in Germany, there was a method permitting a symmetric allocation of blocks while avoiding entry. But incumbents were not symmetric.

trants. Mannesmann made several bids where the smallest free digit (i.e., taking into account the rules that allowed only bids in multiples of DM 100000) was 6, suggesting that it was finally ready to accept an outcome with 6 firms. Initially, DT responded with bids ending in 5, suggesting that it was willing to bid even higher in order to reduce the number of licenses to 5. Only after further price increases and increased nervousness in the stock markets bidding stopped.

6. Concluding Comments

In complex environments it is necessary to base practical auction engineering on a sound theoretical foundation that combines the insights of Auction Theory with those of the body of work known by the name "Industrial Organization". Overlooking market structure details can have far-reaching consequences for the shaping of one of the most important future markets.

Besides allocating spectrum, license auctions shape future market structure in irreversible ways. A successful design must level the playing field among incumbents and potential entrants. The asymmetry among incumbents and entrants is a constant feature of most license auctions, while many other features (such as particular aggregation interests or particular alliances across countries) are of a more transitory nature. Designs that encourage entry will result in increased efficiency, but they will also generate more revenue since more bidders will be attracted by the auction if they perceive real chances of winning.

Finally, given the increased global nature of the telecommunication industry, it may be worthwhile thinking about the advantages and disadvantages of some kind of "European super-auction" that allows the aggregation of continent (or EU) wide licenses besides the national ones. Even if spectrum allocations remain national affairs for the foreseeable future, some harmonization measures may be required. At the moment, many firms have complained that beauty contests always favor national incumbents, while those incumbents (which often got licenses almost for free in their own coutry) can freely compete with deep pockets in other countries'auctions.

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8. Tables

Country	Population (millions)	Spectrum (MHz)	Mechanism (likely)	Licenses	New Entrants
Austria	7.9	145	auction*	4-6	2
Belgium	10.1	140	auction	4	1
Denmark	5.2	155	beauty contest	?	0-2
Finland	5.3	140	beauty contest*	4	1
France	58.4	140	hybrid	4	1
Germany	82.0	145	auction*	6	2
Greece	10.5	140	?	3-4	0-1
Ireland	3.6	155	hybrid	4-6	1-3
Italy	57.4	125	auction*	5	2
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	?	auction	4	?
UK	58.7	140	auction*	5	1

Table 1: European 3G license allocation
(* denotes a completed procedure)

Market Structure	Firm Type	Valuation[43] (£ Bn.)
5 firms, 1 new entrant	large incumbent with 3G license	32.1
5 firms, 1 new entrant	small incumbent with 3G license	22.2
6 firms, 2 new entrants	large incumbent without 3G license	12.5
6 firms, 2 new entrants	small incumbent without 3G license	8.1
5 firms, 1 new entrant	new entrant with 3G license	6.4

Table 2: UK valuations

Market Structure	Firm Type	Valuation[44] (Eu Bn.)
4 firms, 0 new entrants	large incumbent with 3G license	88.4
5 firms, 1 new entrant	large incumbent with 3G license	78.3
6 firms, 2 new entrants	large incumbent with 3G license	47.8
5 firms, 1 new entrant	large incumbent without 3G license	36.3
5 firms, 1 new entrant	new entrant with 3G license	14.5

Table 3: German valuations

UK Licence	**Bandwidth MHz**	**Holder**	**Bid (£ Bn.)**	**Bid (Eu Bn.)**	**Price/MHz (Eu Mil.)**	**Price/Pop (Eu)**
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**

Table 4: Outcome, UK Auction
(* indicates GSM incumbents)

UK Bidders	**Backers**	**Last Bid (£ Bn.)**	**Last Bid (Eu 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**

Table 5: Final Bids, UK Auction
(* indicates a winning bidder)

Dutch Licence	**Bandwidth MHz**	**Holder**	**Bid (Eu Bn.)**	**Price/MHz (Eu Mil.)**	**Price/Pop (Eu)**
A	2×15	Libertel (Vodafone)*	0.713	23.76	44.84
B	2×15	KPN*	0.711	23.7	44.71
C	2×10	Dutchtone (FT)*	0.435	21.75	27.35
D	2×10	Telfort (BT)*	0.430	21.5	27.04
E	2×10	3G Blue (DT, etc...)*	0.394	19.7	24.77
Total	**120**		**2.683**		
Average	**24**		**0.536**	**22.35**	**33.74**

Table 6: Outcome, Dutch Auction
(* indicates GSM incumbents)

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

Table 7: Bidders in the German Auction
(* indicates GSM incumbents;)

Germany Licence	Bandwith MHz	Holder	Bid I. Stage (Eu Bn.)	Bid II. Stage (Eu Bn.)	Price/Mhz (Eu Mil.)	Price/Pop (Eu)
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**

Table 8: Outcome, German Auction
(Debitel left the first stage with a last bid of Euro 5 billion)
(* indicates GSM incumbents)
(# indicates unpaired block of lesser quality)

Austria Licence	**Bandwith MHz**	**Holder**	**Bid I. Stage (Eu Mil.)**	**Bid II. Stage (Eu. Mil)**	**Price/Mhz (Eu Mil.)**	**Price/Pop (Eu)**
1	2×10	3G Mobile	117		5.85	14.8
2	2×10	Connect*(Orange, etc...)	120		6	15.18
3	$2 \times 10 + 1 \times 5$	Hutchison 3G	114	25	5.56	17.59
4	$2 \times 10 + 2 \times 5$	max.mobil*(DT)	119	51	5.66	21.51
5	2×10	Mannesmann 3G#	113		5.65	20
6	$2 \times 10 + 2 \times 5$	Mobilkom* (TI)	121	51	5.73	21.77
Total	**145**		**704**	**127**		
Average	**24.16**		**117.3**	**21.16**	**5.74**	**18.47**

Table 9: Outcome, Austrian Auction
(* indicates GSM incumbents)
(# Mannesmann was a already a service provider, but without own network)

Italy Licence	**Bandwith MHz**	**Holder**	**Bid (Eu Bn.)**	**Price/Mhz (Eu Mil.)**	**Price/Pop (Eu)**
A	$2 \times 10 + 1 \times 5$	Omnitel*(Vodafone)	2.448	97.92	42.64
B	$2 \times 10 + 1 \times 5$	Tim*(TI)	2.417	96.68	42.10
C	$2 \times 10 + 1 \times 5$	Wind*(FT)	2.428	97.12	42.29
D	$2 \times 10 + 1 \times 5$	Andala	2.428	97.12	42.29
E	$2 \times 10 + 1 \times 5$	Ipse	2.443	97.72	42.56
Total	**125**		**12.164**		
Average	**25**		**2.432**	**97.31**	**42.37**

Table 10: Outcome, Italian Auction
(* indicates GSM incumbents)
(Blu* left the auction with a last bid of Euro 2.319 Bn.)