Auctions: How to allocate spectrum rights efficiently*

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Abstract

Through the switch-over from analogue to digital television, a large amount of radio spectrum has been or will shortly be freed up in the 800 MHz bandwidth across the European Union. The question that arises naturally is how to distribute the spectrum rights in the most efficient way possible. This article sweeps through the most common allocation methods in the telecommunication industry and the main relevant theoretical results. In the Spanish case, auctions seem the right way to go but the details are not clear-cut. We perform an analysis of the allocation of spectrum rights in Spain and point out at some potential problems.

Keywords: a*uction, spectrum license, telecommunications.*
JEL classification: *D44, L96.*

Resumen

Debido al cambio de televisión analógica a digital a través de la Unión Europea, una gran cantidad de espectro radioeléctrico ha sido o va a ser liberado en la banda de 800 MHz. Naturalmente surge la cuestión de cómo distribuir los derechos sobre el espectro de la manera más eficiente. Este artículo analiza los métodos de asignación más comunes en la industria de telecomunicaciones, así como los principales resultados teóricos conexos. En el caso español las subastas parecen ser el método adecuado, aunque los detalles quedan por establecer. Realizamos un análisis de la asignación de derechos sobre el espectro en España y señalamos posibles problemas.

Palabras clave: *subasta, licencia espectro, telecomunicaciones.*
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1. Introduction

Radio spectrum is used by a large variety of actors, ranging from television and radio broadcasters to emergency services and the military for their telecommunications, as well as mobile phone and Wi-Fi networks. However, the amount of available bandwidth for telecommunications is relatively restrained, because it requires particular propagation, in-building penetration and antenna-size characteristics that restrict the usable frequency band. Also, spectrum buffers need to be set between the various radio bands in order to avoid interferences between emissions.

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This makes radio spectrum a scarce resource, and it has been historically heavily regulated because of its strategic and economic importance. This regulation has, generally, not only pursued an efficient allocation of the available frequency bands; it has also sought that their use be an adequate one, in order to minimize the possibility of negative externalities between users in the form of interferences. This has lead to strong partition of the spectrum, as each bandwidth is to be used by a different industry for a specified goal using a specified technical standard. Also, it is important to keep in mind that different spectral bands will show different characteristics; some wavelengths may thus be more valuable than others, as well as better adapted for some uses. For example, lower frequencies (such as 800 or 900 MHz) will have better indoor coverage and reach further away than high frequencies (such as 1800 or 2100 MHz), and thus have a higher value for telecommunication networks.

Through the switch-over from analogue to digital television across the European Union to be completed by the end of 2012, a large amount of radio spectrum has been or will shortly be freed up in the 800 MHz bandwidth. This is mainly due to the ability of digital compression systems to allow the transmission of up to eight standard digital TV channels in the same spectrum width as previously used by one analogue channel. This 'digital dividend' is to provide an opportunity to meet the huge demand for new and improved wireless telecommunication services.

Parallel and connected to this, the application of the European Parliament and Council's 2009/114/EC directive coordinates the introduction of a public pan-European cellular digital telecommunication network in the 900 MHz band, as well as allowing for the possibility of opening this spectrum band to any technology compatible with the GSM norm. This 'refarming' permits network operators to introduce broadband Internet connections in a band previously strictly reserved for GSM use. This directive has been strengthened with the European Commission's 2009/766/CE decision to widen the refarming to the 1800 MHz band.

These measures are to have a major impact on competitiveness and growth, as well as providing a wide range of social and cultural benefits, according to the Commission, since it is believed they could trigger yet another IT revolution. Nevertheless, their implementation entails some economic issues that are not yet fully solved, beginning with how to allocate the new 800 MHz spectrum rights efficiently, so as to maximize social welfare and foster innovation. But also how to appropriate and/or redistribute the gains in value of the refarmed 900 MHz spectrum owned by the network operators in order to avoid distortions of competition in the relevant markets. This article will focus mainly on the first issue, *i.e.* on how to efficiently allocate the spectrum rights, although the second problem will also be mentioned when making the recommendations for the Spanish case.

1.1. Learning from past history

Luckily, when trying to design the allocation mechanism, there are some precedents that regulators can use in order to avoid failures. One of the most recent and relevant ones is the release and reallocation of spectrum for 3G telecommunication carried out in Europe in the early 2000s, when new bandwidth got awarded by governments to mobile telecommunication companies through different methods: beauty contests and auctions mostly, or a mixture of both. The allocation mechanisms used then can be an important source of information for the new 'digital dividend' allocation, since they are very closely related cases in which similar spectrum rights are awarded. Lessons could also be drawn from how other European states have organized the allocation of the 'digital dividend'.

TABLE 1
COMPARISON OF REVENUES RAISED IN THE 3G SPECTRUM ALLOCATION IN EUROPE

Country	Year	Number of licenses	Type of allocation	Revenue raised (in millions)
Finland	1999	4	Beauty contests	
United Kingdom	2000	5	Auction	37,000 €
Germany	2000	6	Auction	50,000 €
Austria	2000	4	Auction	671 €
Belgium	2000	4	Auction	516 €
Spain	2000	4	Beauty contest	456 €
Holand	2000	5	Auction	3,000 €
Italy	2000	5	Auction	12,000 €
Norway	2000	4	Beauty contest	36 €
Portugal	2000	4	Beauty contest	400 €
Sweden	2000	4	Beauty contest	12,000 €
Switzerland	2000	4	Auction	128 €
France	2001	3	Beauty contest	1,200 €
Greece	2001	3	Auction	441 €
Ireland	2002	3	Beauty contests	175 €
Luxembourg	2002	3	Beauty contests	9 €

SOURCE: GRETEL Report 01/2007.

This article follows a collection of papers written by Paul Klemperer and compiled in his 2004 book, *Auctions: Theory and Practice,* and it is structured in three main parts. First, we present the different reward mechanisms used for spectrum allocation in detail, as well as their respective advantages and disadvantages. We then continue with auction theory and its main result –the revenue equivalence theorem–, and the main aspects the policy-maker needs to consider when designing an effective allocation method, putting special emphasis on examples from the 3G experience. Finally, we describe some general recommendations for a good auction design and particularize them for the Spanish case.

2. Allocation mechanisms

Before we talk about awarding methods, let us extend our discussion about the objectives of a government when freeing bandwidth. In general, or at least so do economists like to think, a government should be concerned about general efficiency. That is, a government should try to have as much value-added produced in its country as possible through the bandwidth release. In the particular case of spectrum rights, this objective is reached by awarding them to the firms who will use them in the best and most efficient ways. Now, these firms are also the ones willing to bid the highest for these rights in an auction, since they would earn the most from them. Therefore, any mechanism that awards the rights to the firms willing to pay the most is an efficient one.

Generally, the regulator tries to find an equilibrium point between static and dynamic efficiency. In a few words, it is as important to assign frequencies to the company that values them the most –static efficiency– as guaranteeing low final prices through solid competition afterwards –dynamic efficiency. If there are enough firms in the market, they will start competing for consumers through lower prices and better service, which would generate higher investment. In this sense, the number of licenses offered plays a key role, as we will see in detail further on. With this goal in mind, potential collusion and number of participants in an allocation process will be the most important aspects for the design process. These are very important issues, and shall be dealt with during the planning of the allocation mechanism.

But should revenue raising be an objective in itself? Governments need to raise revenue for different reasons: social policies, operating costs etc. The use of taxation such as the VAT or income taxes carries deadweight losses, since it either increases the price of goods or decreases the proceeds of labor. As such, it reduces the optimal quantity of both goods and labor and thus raises less revenue than it at first should. Economic theory tells us that if feasible (hardly ever the case, due to distributional issues), lump-sum taxes should be used, as they do not create any distortions. In brief, typical revenue raising schemes create distortions and are thus costly to enforce.

In this line of reasoning, auctions can be interpreted as a lump-sum taxation, that doesn't produce distortions. Once a telecommunication firm pays for the license, this decision does not reduce the investment in the new technology nor does it affect future prices: we say that "by-gones are by-gones". It is a revenue raising mechanism that is more efficient than proportional taxation, especially since it is voluntary, *i.e.* networks participate and pay for licenses only if it is worth it, if they expect to make profits out of it. If one was worried that networks might end up paying more than their fair share, it would still be socially optimal to raise as much revenue as possible through the allocation of licenses and then possibly reduce the future taxes paid by the networks and thus reducing part of the distortions. That is, one should not worry if a bidder pays what seems too high of a price, in the same way as one shouldn't grant compensations to people acquiring houses or shares at the peak of a housing or stock-market boom, as an auction theory specialist, Paul Klemperer, uses as a visual analogy.

Therefore, since an allocation mechanism must be found to award the spectrum rights in any case, it is socially optimal to raise as much revenue as possible from it. We can therefore safely state whether an allocation mechanism was a resounding success or not based on the amount of revenue it raised.

The same reasoning applies to the claim that raising a one-off payment for the spectrum rights is more efficient than paying *ex-post* royalties on the license. Although royalty payments may be better modulated to the actual value the network operator extracts from its license, they act as an indirect tax, reducing incentives to pursue maximum efficiency in the spectrum use. Also, unlike a unique payment, they may be passed on at least partly to the consumers, thus creating dead-weight loss and reducing social welfare.

The allocation methods most generally used are auctions, beauty contests and historically also lotteries. Just to give an example, in the 3G spectrum allocation of 2000-2002, half of the countries used auctions while the other have allocated the licenses through beauty contests.

2.1. Beauty contests

There are different ways in which regulators can allocate licenses, one of the preferred alternatives to auctions being beauty-contests. Although *ex-ante* they present a lot of appealable features, they rely mainly on subjective criteria which can usually be debatable.

Beauty contests have a long history in spectrum allocations. A significant number of European countries held beauty contests in order to allocate 3G spectrum rights between 2000 and 2001, including Finland, France, Ireland, Norway, Portugal, Spain and Sweden, so it is important to devote a subsection to its advantages and disadvantages.

In beauty-contests, the policy-maker directly determines the most qualified firms for maximizing social welfare and licenses are granted based on a comparative study. Generally, the government announces the criteria that it is going to value in the project, and then firms decide to participate or not. Its main advantage is that, at least in theory, the right to operate is given to the companies that seem the most likely to take advantage of it. On the other hand, it is very subjective and there are high risks of lobbying, which implies that efficiency can become a mere utopia: it is highly probable that the most organized parties will be awarded the license rather than those that value it the most.

Those in favor of such assignment mechanisms argue that procurement decisions based on price alone may endanger other important attributes such as quality and service. This is why a combination of beauty contests and auctions is sometimes used. They are generally designed as follows: in a first stage the companies with the best projects and the ones with financial solvency are chosen (which is also meant to prevent entry by speculators) and then the good or the license is allocated to the firm that values it the most. This mechanism is not as reasonable in cases of concentrated markets (as in the telecommunication industry in Spain) where the policy-maker is interested in attracting entry in the sector to foster competition *ex-post,* not in limiting competition in the auction stage.

Nevertheless, it is important to remember that, as the British communications regulator (Ofcom) states, it is difficult to keep the selection procedure objective, non-discriminatory and transparent, as required by the EC Licensing Directive. As such, there is the possibility of appeal against non-selection, leading to lengthy judicial review that could delay the award of licenses. Also, setting selection criteria and evaluating against them can both be difficult processes and a beauty contest tends to favor established companies, who can cite a track record in support of their case. Moreover, the selection procedure can be a lengthy process, particularly where a large number of licenses are on offer. Finally, because it is a subjective process, there is no guarantee that it will place spectrum in the hands of those best able to use it to maximum economic advantage.

2.2. Lottery allocations

Historically, lotteries were another important allocation system. They were used in the US when the number of licenses to be granted increased considerably and, due to the time constraints beauty-contests were not an option any longer.

In the US 3G spectrum case, lottery winners were often speculators with no experience and no intention of operating such a license. This was aggravated even more by the fact that licenses could be resold, which encouraged entry by inexperienced speculators. This design implied a strong fragmentation of the spectrum that delayed the upturn of investments and new technologies with, as a result, a degradation in consumer services.

Lotteries are simply an arbitrary allocation of resources. They have the advantages of simplicity and transparency, but their strong disadvantages have rendered them obsolete and nowadays they are not used for spectrum allocation.

2.3. Auctions

Auctions are mainly divided in two types: static and dynamic. These are sometimes referred as closed and open auctions.

1. In **dynamic/open auctions** participants may repeatedly bid and are aware of each other's previous bids. The most common ones are the English and the Dutch auctions.

- In an *ascending* or *English auction* (also known as an *open ascending price auction*) bidders successively raise their price until no one is willing to increase the bid and the winner pays the last highest bid. This is the auction typically used in sales of art. A variation is the Japanese auction in which the price continuously and participants quit until only one player remains rises.
- In a *descending* or *Dutch auction* (also known as an *open descending price auction*) the price starts high and keeps decreasing until one of the bidders states his willingness to buy. The main difference with the ascending auction is that it has only one round: the first player that shows his will to buy the object is the winner. For this reason it is thought to minimize the time it takes to assign the product. This is why it is very much used in auctions of perishable goods such as flowers and fish.

2. **Static/closed auctions** are one-stage games in which players do not observe other players' activity. The most common types are the following:

   - *First-price sealed-bid,* where everybody submits a bid in a closed envelope and the highest bidder wins, paying his bid price;
   - *Second-price sealed-bid,* where the highest bidder wins, paying the second highest bid.

Although they sound completely different, there is equivalence in strategies between the dynamic and static auctions under some assumptions. To illustrate this, note that the descending auction is essentially a static problem: each bidder chooses the price at which she is willing to buy and pays the price at which she called out (virtually the player does not even have to be in the room: she could send a "delegate" with this complete book of instructions). It is strategically equivalent to a first-price sealed-bid auction.

In the same vein, the ascending auction is strategically equivalent to the second price auction under private values[1] plus a number of additional conditions. In the case of common values the bidders' valuation of the good depends also on the other players' valuations as they are signals of what the good is actually worth and the equivalence does not hold any longer. The one that bid the highest probably overvalued the good as her estimation of its value exceeds all other players' valuation. This is what is known as the winner's curse. In order to prevent potential losses, bidders will tend to bid more cautiously in the open auction as they continuously receive signals about the good's value.

[1] In private value actions, bidders know their own value, which does not depend on the value of the other participants.

In the last two decades auction theory has become increasingly popular as its use was widely extended for procurement, license allocation, privatization of firms, etc. In this direction, the Nobel award in economics in 1996 was granted to one of the main contributors in this field, William Vickrey. In Europe, although traditionally beauty contests were used, about half of the countries opted for an auction-based method for the allocation of 3G spectrum rights. One of the success stories is the case of the UK, which raised revenue as high as 37.000 million € (650 € per capita). On the other hand, Spain chose a beauty contest and raised only 456 million € (11 € per capita). Nevertheless, as we will argue in the second part of the report, not all auctions were as successful as the British one.

Why have auctions become increasingly popular? People in favor of auctions highlight that the advantages of using auctions as a market mechanism in the allocation of resources are mainly efficiency and revenue raising by the regulator. This is so because an auction simply creates a market by putting buyers and sellers together and facilitates trade, thus duplicating all the market outcomes.

Now, given that markets will reach efficient outcomes, why worry about initial allocations? Why not simply choose the simplest mechanism (maybe a lottery) and then let agents trade in a secondary market? Because efficient initial allocation matters in presence of transaction costs. In this case, although re-selling is an option, the efficiency in secondary markets may take very long to be reached, thus reducing investment and service quality, as seen in the US case with lottery allocations.

We argue that auctions are the best allocation mechanism. First, these achieve static efficiency as they assign the good to the agent that values it the most. Moreover, if the auction is properly designed in order to attract bidders, it will also achieve dynamic efficiency. And finally, auctions do not create any distortions as they can be viewed as a lump-sum tax paid by the winner according to her expectation of future profits.

So, what is the best auction? What aspects should be taken into account when designing such a process? This is what we will try to answer in the next section.

3. Auction Design

The main result of auction theory is the **revenue equivalence theorem**[2]. it applies both to private and common values as long as bidders' valuations are independent. In brief, any auction mechanisms satisfying a number of assumptions will raise the same expected revenue.

[2] The theorem was first derived in an elementary form by VICKREY (1961, 1962) and subsequently extended to greater generality by MYERSON (1981), RILEY and SAMUELSON (1981), and others. We present below the version as in Klemperer, *Auctions: Theory and Practice:* "Assume each of a given number of risk-neutral potential buyers of an object has a privately-known signal independently drawn from a common, strictly-increasing, atomless distribution. Then any auction mechanism in which (i) the object always goes to the buyer with the highest signal, and (ii) any bidder with the lowest-feasible signal expects zero surplus, yields the same expected revenue (and results in each bidder making the same expected payment as a function of her signal)".

One consequence is that, under the assumptions of the revenue equivalence theorem, *all the standard auction are optimal* if the seller imposes the *optimal reserve price* and all the bidders have the *same ex-ante probability* of winning the auctioned good. Nevertheless, most of the assumptions needed do not usually hold in practice. For example, incumbent firms tend to value an operating license consistently more than entrants, and thus will consistently be more likely to win the auction by bidding more. This implies that most times the devil is in the details, so, when designing an auction, it is important to keep in mind that the game begins long before the auction itself and a good knowledge of each market is fundamental in order to set the right pillars. Generally, two aspects of the auction design that are crucial are entry and collusion.

3.1. Entry

Why is entry important? Can we actually put a value on the number of bidders? In this case, common sense and economic theory go hand in hand. Bulow and Klemperer (1996) found that a simple ascending auction with no reserve price and a given number of symmetric bidders is more profitable than any auction that can realistically be run with one player less. The higher the number of participants, the higher the expected price of one license, as participants bid more aggressively because they fear that others may be willing to offer a slightly higher price and thus win the contest. Consequently, it is better (in terms of revenue raised) to expand the market and attract more bidders rather than devoting resources to a perfect design.

In the case of spectrum licenses and other specialized assets, few potential bidders are likely to value them highly. To obtain a high price, the seller must identify and attract the most likely purchasers, so independent marketing to seek out such bidders can be especially valuable. In practice, auctions for valuable yet highly specialized assets often fail because of insufficient interest by bidders, as happened in the 3G spectrum allocations in Switzerland, Austria, and Italy. Weak bidders can simply be scared off, as they are not going to devote time and money for an auction that they are very unlikely to win at a favorable price. Besides, players may simply refuse to bid in designs that are considered strange or unfair.

As mentioned previously, sufficient entry is generally determinant for success stories. Take for example Switzerland, which had the misfortune of mimicking the British design in November/December 2000 to award four licenses (that had turned up to be very effective for the British telecommunication market). Not only were entrants put off by the ascending auction design (at least one company hired consultants and drew off after learning that the auction design would give the company little chance against stronger incumbent opponents), but the Swiss authorities also allowed joint bidding for licenses. This in essence sanctioned collusion, and shrank the number of participants from nine to four joint ventures in the week prior to the auction. At that point, the Swiss government postponed the auction for a month in order to redraw the rules, as it realized the outcome could turn out to be a failure, but the potential bidders successfully argued that the initial rules were legally binding. Therefore, the bidders only had to pay the reserve price, which was misguidedly set too low, and the auction only raised 20€ per capita.

This case study also highlights the bad use of reserve prices. Authorities have a tendency to set a low reserve price, probably in the misguided belief that this will lure more bidders in. Nevertheless, as can be seen from this example, one should put a reserve price high enough to ensure that, if the mechanism turns out not to be that robust and sufficient entry is not met, the expected revenue raised still attains a certain threshold. This is especially true if previous auctions of the same type have already been carried out and information of possible valuations for the licenses is available, so as not to set the reserve price too high. In this case the designer of the auction faces a trade-off between encouraging entry by setting a low enough reserve price, and placing a lower bound to the revenue raised with a sufficiently high one.

Maybe the setting of an appropriate reserve price would also have changed the outcome in Belgium and Greece given that they had the particularity of not being very attractive markets and thus did not even manage to attract as many bidders as licenses available. Their auctions, in March and July 2001 respectively, not only took place at a time highly dented by the economic crisis, but their markets also did not look very profitable. For example, Belgium presented a very dominant incumbent, with two-thirds of the mobile phone market, probably favored by the state. Both auctions licensed four frequency blocks and attracted only three bidders, who therefore paid the reserve price, with a total revenue of around 45€ per capita raised.

It is difficult to argue that the design of the auction was flawed when one of the licenses got unsold. More plausibly, its timing is to blame, since analysts' estimates of license valuations were at that time around 50€ per capita, or around one-tenth of the levels predicted the year before. The only thing these countries could do is set an appropriate reserve price in order to raise as much revenue as possible.

The Italian auction also turned out to raise little revenue due to insufficient entry. The Italian government held its 3G ascending auction in October 2000. It planned to award five licenses, but threatened to lower this number in case not enough serious bidders participated. This was to avoid the failure of the auction (just as had happened in the Dutch case, that will be mentioned later on) by making sure there would be enough competition for the licenses. In the end only six bidders entered the auction, just enough for the number of licenses not to get reduced, but one of the entrants quit after less than two days of bidding. The price did therefore not rise much above the reserve price, and the auction raised 240€ per capita in revenue.

Although reducing the number of licenses if not enough competition took place made sense to the government, it probably had the wrong viewpoint, since the emphasis should probably have been on attracting entrants, not on making the established firms compete. On top of this, reducing the quantity of auctioned licenses could have concentrated the mobile phone market too much *ex-post* and thus might have raised concerns about its effect on competition.

Nevertheless, it is important to remember that firms had already learned through the auctions held in other countries prior to the Italian one that incumbent firms were willing to bid highly for licenses. Also, the dotcom crisis in the early 2000s was underway and dented into previsions of expected future profits of technology firms, as well as market valuations and sources of funding. Therefore, the later the 3G auctions were held, the less revenue they could be expected to raise. The fact that the auction didn't raise as much revenue as expected is thus clearly not the sole fault of the Italian auction design.

As we have seen from the previous examples, if the policy-maker wants to attract bidders, a crucial point is the decision to set the number of licenses auctioned. In the case of spectrum auctions, the market is very concentrated in many countries and if the number of licenses is low, this could deter entry of new competitors given that they face a disadvantaged position in the form of less information or higher initial costs. But how can the design of auctions encourage participation?

Although there is no general theoretical result, we could still say that setting a first-price rather than a second-price sealed-bid auction will potentially attract more bidders, because strong buyers prefer the second-price sealed-bid auction, whereas weak ones prefer the first-price auction. The reason for this is that in the second-price auction, the optimal action is to bid one's valuation (whereas actually paying less, *i.e.* the losing bidder's valuation), so established incumbents which tend to value the licenses more have an advantage; meanwhile, since they will try to bid less than their valuation in a first-price auction, the entrants have more probabilities of winning the license by bidding more aggressively. As such, Maskin and Riley (2000b) prove that a strong bidder will extract more expected profit from a second-price than from a first-price sealed bid auction, while the reverse is true for a weak bidder.

This result can be extrapolated to ascending English auctions, which are in fact very similar to second-price sealed bid auctions in term of bidders' strategy, since in both cases players find in their best interest to bid up to one's true valuation. Moreover, in the case of a dynamic ascending auction, strong bidders can re-evaluate the situation continuously and thus may be even more susceptible of winning than in a second-price sealed bid, obstructing entrants' chances even more. Nevertheless, a possible mechanism to deal with this issue could be the Anglo-Dutch auction (in which an ascending auction eliminates all but two bidders or, in the case of a multi-unit auction, all bidders but the summer of objects plus one, who then compete with sealed bids).

Moreover, entry is also deterred if the cost of preparing the auction is high with respect to the probability of being granted the license. In order to increase participation, it may be sensible to increase the probability of the weak bidders to win or reduce the costs of participating. To this purpose, an auctioneer may wish to run an *ex-post* inefficient auction to attract weaker bidders to enter the contest and make stronger players bid more aggressively (closer to their true valuations)[3]. As described in detail below, there are several tactics that can achieve this.

[3] See MASKIN and RILEY (2000a).

One possibility is for the policy-maker to set aside some licenses for which only the "weak players" could bid, where the "weak players" could be small businesses, new companies willing to enter the market, etc. In the case of the telecommunication industry, if new entrants know that they will only have to compete amongst themselves for some licenses, they might realize that the chances of winning at least one license are considerably higher, making them more willing to incur the preparation costs.

Another possibility is to allow favored bidders who outbid non-favored bidders to pay only a fraction of their winning bids (in some auctions this threshold was set between 65 per 100 and 85 per 100, but this strategy could face legal difficulties). In line with the previous argument, the chances of winning are higher. This will encourage entry and make strong players bid more aggressively, thus increasing the expected revenue.

3.2. *Collusion*

Whenever there is a reduced number of participants, collusion becomes an issue as in any concentrated market. Among the limited research on the topic, Robinson (1985) argues that a collusive agreement may be easier to sustain in a second-price auction than in a first-price auction, since the optimal agreement would be for the designated winner to bid infinitely high while all other bidders bid zero. The winner will pay a price of zero for the license and will divide all the revenues with the other participants, or simply bid low on markets of potential interest for the competitors. Meanwhile, in the first price auction all participants have a substantial incentive to cheat, as bidding slightly above zero will increase their possibilities of being granted the license. Also, dynamic auctions such as ascending ones can favor collusion more than static auctions, because participants can retaliate and punish deviators in them, as well as communicate with each other more easily.

Potential collusion can become very important, as the Austrian case in November 2000 highlights. The Austrian auction design copied the German one explained later on, with an ascending auction in which twelve spectrum blocks could be divided in either four or six licenses. Again, the ascending design disincentivized entry as only six bidders competed for the licenses. As could be expected, these bidders decided to settle for the six-license setup (since reducing the number of licenses would have pushed their price very high in order to drive out other competitors) and stopped bidding just above the reserve price, which had been set very low. It was rumored that these few rounds of bidding were actually just meant to create some perception of competition as in fact the largest incumbent, Telekom Austria, had said before the auction that it "would be satisfied with just two of the twelve blocks of frequency on offer and if the [five other bidders] behaved similarly, it should be possible to get the frequencies on sensible terms", amounting to an offer of collusion. The Austrian auction raised only 100 € per capita.

3.3. Multiunit auctions

Most of the times auctions for spectrum licenses are multiunit. That is, a given company can bid for different goods or licenses simultaneously.

The particular feature of a multiunit auction is that the value of a license to a bidder is not fixed, since it will depend on the other licenses that the firm receives if licenses are either substitutes or complements. If acquiring one license makes the bidder willing to pay more for a second one, then these are *complements*. If the contrary happens, they are *substitutes*.

The design problems for these auctions include not just the usual ones about getting incentives and allocations right, but also limiting the complexity so that costs incurred by bidders are not too high and the reliability of the system is maintained. If bidding on all items takes place simultaneously, bidders can respond to changing relative prices, which implies that bidding should also end simultaneously in order for opportunities for substitution not to disappear.

An example of a multiunit auction design is the FCC auction for the 3G spectrum in the US designed by Paul Milgrom and Robert Wilson. They proposed a simultaneous multiple round auction with a simultaneous closing rule. It imposed a cost on holding back by tying a bidder's level of eligibility in future rounds to its activity level in the current round. If the bidder was not active on a minimum percentage of the quantity of spectrum for which it was eligible to bid, it suffered a permanent loss of eligibility, which discouraged bidders from holding back and staying inactive.

3.4. Successful 3G spectrum auctions

As we have seen so far, auction design is not a simple task, since one needs to take into account idiosyncratic characteristics of each particular market in order to set the right incentives. At this stage we will present the design of three success stories: United Kingdom, Germany and Denmark. As will become clear, each of these auctions was designed following the particular characteristics of each market, although the German auction's favorable outcome could be attributed more to good luck than to sound auction design.

The UK ran the first 3G auction in the EU in March 2000. At first, only four licenses were to be sold, due to technical constraints. Since there were also exactly four incumbents in the mobile phone market, the government was worried that an ascending auction would deter entrants from entering the auction and bidding altogether. In that case, the incumbents could divide the market and buy just one license each at the reserve price, *i.e.* the minimum bidding price.

This concern arose because, in a simple ascending auction, incumbents can outbid entrants at each point. Because they are already established, incumbents expect to earn more from such a license and are thus willing to pay more for it than entrants. So entrants know that they basically have no opportunity of winning the auction against incumbents and have no incentives to enter the auction, especially if this process is costly and time-consuming.

The designers of the UK auction therefore wanted to run a hybrid of the ascending and sealed-bid auctions, where an ascending auction would take place until only five bidders remained. These bidders would then compete on a fourth-price sealed-bid auction for the four auctions, meaning that the four highest bidders would pay the same price for each license. This design was intended not only to level things up for entrants, but also to deter collusion in the last stage.

Nevertheless, it finally became possible to sell up to five licenses. Since no bidder was allowed to buy more than one license, and licenses could not be divided, tacit collusion between the incumbents was not feared anymore. The designers then decided to revert to the easier English auction while reserving one of the available licenses for an entrant. This turned out to be sufficient to attract entrants, since up to nine new entrants bid seriously against the incumbents.

Due to this accrued competition, the government managed to raise 650€ per capita during the auction. Regarding this revenue, it is important to remember that since five licenses were sold, the actual price each firm paid for its license was determined by an entrant, *i.e.* it was the price at which the sixth firm (the second entrant) did not want to buy a license anymore. This clearly shows how large and committed entry in an auction can be beneficial in increasing revenue.

Germany's auction in July 2000 was a more complicated type of ascending (English) auction in which the number of licenses in play was variable. In that sense, there were twelve spectrum blocks to be divided either in four or six licenses, that is, bidders could decide whether they preferred to buy at most one license of three blocks or one of two blocks. The reasoning behind this more complicated scheme was to allow the bidders, who might have had information unavailable to the government, to decide upon the advantages of larger versus small licenses taking into account their relative price.

Also, the auctioneers thought that such a setup could encourage competition by allowing for a shortening in the number of licenses awarded. On top of the possible engineering advantages of having more spectrum blocks, if only four licenses were to be awarded, then a more concentrated and possibly more profitable mobile phone market would arise, making the three-block licenses more interesting for firms, although competition concerns could arise in the future.

The auction only attracted seven bidders, and one of them (Debitel) was offered very early on in the bidding stages to become a virtual network operator using a competitor's (MobilCom) network "while saving on the cost of the license". These remarks didn't bring about any punishing reaction from the government, and although Debitel did not quit immediately, it stopped its bidding at around 55 per cent of the revenue per capita achieved by the UK auction, probably due to the higher attractiveness of the outside option.

What is striking in the German auction is what happened next: the remaining bidders could have just stopped bidding and paid relatively little for the licenses, but they did not. Actually, Vodafone-Mannesmann did end a number of bids with the digit "6", which was understood as a desire to set for six licenses at the given price. But Deutsche Telekom continued to raise the stakes until the bids approached the level at which the weak firms left the UK auction and then it stopped[4].

This strategy did not make sense if the goal of Deutsche Telekom was to reduce the number of licenses to just four, as if this had been the case it should have kept pushing the price up until the weak bidders quit. It would actually make more economic sense to push the price upwards when it is already close to the weak bidders' valuation threshold, and they are thus more likely to quit the auction, than when it is far from it thus makes no economic sense to push the price up until slightly under that critical threshold and stop there.

Nevertheless, Deutsche Telekom's objectives may have been altered by the fact that it was majority-owned by the German government and it may have received political pressure to push prices upwards in order to guarantee the success of the auction from a political viewpoint. In any case, the German authorities managed to raise 615€ per capita, a figure very close to the British one.

The Danish auction was the last of the western European auctions, in September 2001, and was to award four licenses in a market with four incumbent operators. In order to avoid the same problems as previous European auctions, Denmark chose to run a sealed-bid auction instead of an ascending one, so as to foster entry and thus competition.

Although the estimates of the valuations were still very low, the Danish auction managed to raise around 95€ of revenue per capita through its sealed-bid auction, almost doubling most estimates. This success was achieved by attracting a committed bid from a new entrant, which actually drove off one of the incumbents from the auction. Since this incumbent would probably continue to participate in the market as a virtual network, not only did the auction raise more revenue than expected, it also increased competition between the mobile phone network operators.

After having analyzed all the elements that need to be considered when designing an auction, one can easily conclude that there is no one-size-fits-all kind of argument. Different markets may seem to be very similar, with only minor differences, but, as we have seen, details do matter and we should take them into account. The most obvious example of such a mistake was the auction for 3G spectrum in the Netherlands.

The Netherlands' auction followed the British one in July 2000, and since the first was such a success, it tried to replicate it without taking into account its local circumstances. There were five licenses to award, and also five incumbents in the

[4] The two weakest bidders in Germany, notwithstanding Debitel, had also participated in the UK auction and had quit close to the end. One of them had announced prior to the German auction that it was willing to pay the UK price.

market. Due to the equal number of licenses and strong bidders, it could be predicted that very few entrants would show up, and thus not enough competition would ensue (and indeed some economists such as Paul Klemperer and Emiel Maasland did predict it).

Indeed, this is what happened, since only one entrant (Versatel) bid and it withdrew after receiving threats of legal action by one of the incumbents (Telfort). Telfort claimed that Versatel "believes that its bids will always be surpassed by bids of the other participants" and that it was just "attempting to raise its competitors' costs". The government took no action in this matter and the auction finalized as expected, with the incumbents buying all the licenses for just 170 € per capita raised.

4. Recommendations

Obviously, the examples stated previously are a clear reminder of the importance of the auction design with regards to its outcome. Also, as they clearly show, there is no clear-cut one-size-fits-all model that one can use to efficiently allocate licenses in any scenario, since each auction is different and thus needs different specifications.

Nevertheless, we can try to infer valuable lessons for the Spanish case, if an auction, as opposed to a beauty-contest, were to take place to allocate the spectrum rights. For this, we will not only look at the already stated 3G examples but also at the German 4G auction in April-May 2010.

Germany conducted a unique ascending (English) multi-unit auction to allocate spectrum rights in the 800, 1800, 2000 and 2600 MHz frequency band, raising over 4.3 billion €. Six licenses of 2x5 MHz Frequency-Division Duplexing (5 MHz FDD from now on) where auctioned in the 800 MHz band, the most valuable one, and Telefónica, Vodafone and Deutsche Telekom each got two of them, at an average price of 600 million € each. The fourth incumbent, KPN, dropped out of the auction and will have to work as a virtual network operator in that bandwidth. There seemed to be enough competition for the licenses (four incumbents for three packs of two licenses each) and a simple ascending auction mechanism was thought to be enough, probably since no further entry of potential competitors was needed or pursued.

4.1. Spain is different

At first sight, it seems the Spanish setup, as proposed by the Ministry of Industry in its project of Royal Decree regarding radio spectrum, mimics quite closely the German one, with also six 5 MHz FDD licenses available in the 800 MHZ band, as well as multiple licenses in the 1800 and 2600 MHz frequency bands. Therefore, an early-on advice for the allocation of the 'digital dividend' spectrum would be to mimic the Germans. Although, to be honest, this strategy seems to be generally sensible for many economic issues, let us not forget the fate of the Austrian 3G auction, which replicated its northern neighbor's design without paying close attention to local idiosyncrasies. Also, the German auction's raised revenue fell far short of what some analysts predicted and, although being a windfall for German state coffers, it compares very negatively to the 50 billion € raised by the 3G auction.

We have seen previously that the most important issue in designing an auction is the competition that it will foster. In Spain, contrary to Germany, there are nowadays only three incumbents in the 900 MHz band, while another firm (Yoigo) only has rights in the 2100 MHz band. Therefore, one could expect three firms competing for the 800 MHz rights, although Yoigo or any other entrant could also make a move. As for the licenses in the other frequency bands, the German example again shows that they are not that valuable (or not that scarce) and should thus not be very important in the auction's outcome.

Nevertheless, another possibly crucial difference between both countries is that spectrum rights in the 900 MHz bandwidth in Spain will also be reshuffled, refarmed and reallocated together with the 'digital dividend' spectrum, allowing for technologies other than the traditional GSM to be used on that frequency span. In return for the refarming, the regulator has called back 4.2 MHz of FDD bandwidth, which added to a free spectrum of 0.8 MHz will allow it to issue a new license of 5 MHz, for which Vodafone and Telefónica will not be able to bid. On top of that, some existing spectrum rights of Movistar will expire in 2015, freeing two more licenses (5 and 4.8 MHz FDD). In other words, the Spanish regulator is planning to issue six licenses in the new 900 MHz band and three in the refarmed 800 MHz band (one of the licenses being slightly smaller than the others), as well as a number of licenses in the other bandwidths. All these licenses will expire in 2030, although two of them in the refarmed band will only be available from 2015 onwards. Moreover, Vodafone will keep two licenses in the 800 MHz band, while Movistar (Telefónica) and Orange (France Télécom) will keep one license each, all of them expiring in 2020.

Moreover, firms will not be allowed to own or operate on more than 20 MHz FDD in the 800 and 900 MHz bandwidth put together, and a limit of 55 MHz will apply in the combined 1800, 2100 and 2600 grid. Also, any firm owning 10 MHz or more in the 900 MHz band will have to allow for virtual networks using its grid. All these regulations are obviously meant to keep sufficient competition in the ensuing market and make economic sense, but they might nevertheless complicate the allocation procedure and make its outcome more uncertain.

As an example, one would expect a 5 MHz license to be valued more than a 4.8 MHz one. However, since owning 10 MHz of spectrum forces one to open its network to competition, it might actually make more sense to keep only 9.8 MHz of rights, thus making the smaller license more valuable.

Also, it is important to notice that, with the refarming of the traditional GSM spectrum, both the 800 MHz and the 900 MHz band will have very similar valuations, since both will be open to any technology and their frequency ranges are very close and thus share the same characteristics. Therefore, the availability of the 'digital dividend' spectrum has a quantitative value, as opposed to a qualitative one, because network operators expect a large increase in mobile broadband Internet access demand and thus seek to increase their capacity in order to avoid future potential congestion problems.

This increase in capacity could be carried out by increasing the efficiency of the use of existing spectrum, by building more base stations (antennas) or by using more spectrum (buying new spectrum rights and upgrading base stations). There are advantages as well as limitations to each of the different options: for example, ameliorating spectrum use by upgrading software is very cost-effective, but can only lead to a limited efficiency gain, whereas introducing next generation technologies is far more expensive, and requires sufficient penetration in customer devices to support it. Meanwhile, building a more concentrated net of base stations is expensive, whereas the upgrade of the antennas to new spectrum is relatively cheap, but requires buying new licenses. Therefore, the price that network operators will be willing to pay for the license will also depend on their outside investment options.

4.2. What to do

Put together there are thus nine licenses to seize in the 800 and 900 MHz band, with four more in the hands of the three incumbents until 2020, thirteen in total, while no firm can own more than 4 licenses, *i.e.* twelve in total. Therefore, the success of the auction rests fully on the entrants, since if only the three incumbents bid, they could buy their licenses for the minimum price. If indeed an entrant sought to build a network, it would probably need more than just one license in order to avoid congestion, thus increasing competition for the rest of the licenses. In this sense, the fact that in the no-entry scenario one of the licenses would be left unallocated may be a good incentive for new entrants to bid in the auction. On top of that, let us not forget that Vodafone and Movistar will be barred from bidding for one of the 900 MHz licenses, the only one in that band starting before 2015, thus further increasing incentives for entry.

But who could potentially enter the auction to bid for one of the licenses? There are a large number of mobile virtual network operators (MVNOs) in Spain who could bid for a license, as well as Yoigo, which is not considered a MVNO since it owns some bandwidth but is in fact a virtual operator in the GSM band. However, most of these operators are far too small to buy a license, both because of the financial burden it would represent, but also because of the lack of profitability of their small share of the market. The only operators who could participate in the auction are probably Yoigo, which is the largest of the "small" operators with just under 4 percent market share[5], and Simyo, which is owned by KPN (one of the participants in the German 4G auction), although it is even smaller.

[5] See December 2010 monthly report, Comisión del Mercado de las Telecomunicaciones (CMT).

Therefore, there will probably not be enough competition for the amount of licenses to be allocated. In this case, maybe other designs than the ascending English auction could be set up, as for example a first-price sealed-bid auction, which is better suited to foster entry (the Anglo-Dutch auction is not well adapted for a multiunit auction where participants can buy a variable number of licenses). Also, a reduction in the bandwidth auctioned, *i.e.* in the number of licenses, could be envisaged, maybe leaving some free bandwidth for unlicensed use by the public (as the FCC is to do in the USA with part of its spectrum below 700 MHz).

In any case, the auction should entail clear-cut and sensible rules on minimum bids (preferably relatively high, in case the auction goes wrong), as well as on minimum or binding increments (to avoid dragging the process forever and limit communication possibilities between bidders) and minimum activity levels if the chosen auction design is a dynamic one. Also, one should try to punish communication amounting to collusion or threats between firms.

Finally, it is important to remember that, even if the auction does not raise an impressive amount of revenue, as is likely to be the case in Spain due to the probable lack of competition for the licenses, it can only be higher than in a beauty-contest if one sets the minimum bidding price accordingly. This is not a trivial issue given the state of the Spanish public coffers and its current economic circumstances. Also, in order to foster the efficient deployment of networks, one can set rules governing the minimum amount of investment or the speed of deployment (as Germany has done) that the firm has to follow in order to keep the ownership of the license. Therefore, an auction designed following this advice could and would be strictly better than any beauty contest, which is why we advocate its use in the forthcoming allocation of spectrum rights in Spain.

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