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Recommendations for the Optimal Allocation of Radio Spectrum Licenses in the European Union

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Abstract

Auctions are used by many organizations to assign property rights for a wide variety of goods. In our paper, we are concerned with the use of auctions by the European Union to assign radio spectrum licenses. Without state involvement, firms use the radio spectrum until its value is dissipated. Thus, it is preferable for the state to assign and enforce radio spectrum rights. Further, because of the non-competitive structure in the telecommunications market, it is also preferable for the state to assign radio spectrum rights in such a way so as to encourage new entrants. Of the available allocation mechanisms, auctions are the most efficient in assigning rights and encouraging a competitive market. Of the available auction designs, a combinatorial auction provides several key advantages over others in encouraging efficient allocations, permitting new entrants, and allowing bidders to optimize dynamically. Drawing on evidence from the European Third Generation auction and the Federal Communications Commission auctions, we conclude that the European Union could improve social welfare by centrally allocating radio spectrum licenses using a combinatorial auction.

1 Introduction

An economist is someone who sees something working in practice and asks whether it can work in theory.[1]

The evidence shows that auctions work both in theory and in practice. From art to energy contracts, from flowers to EBay, auctions are used to efficiently allocate resources and generate revenue. In the last two decades, auctions have become a more popular means of assigning licenses to the radio spectrum. However, despite their economic appeal, several nations fail to utilize these auctions to their full potential (or at all

[1]We are not sure where this pithy phrase originates, however the first recorded use is attributed to Ronald Reagan in a 1987 speech.

in some cases). We argue that the European Union could improve social welfare by centrally allocating radio spectrum licenses using a combinatorial auction.

In Section 2, we provide background information covering the radio spectrum, transmission, and basic auction terminology. In Section 3, we survey the relevant literature concerning auctions and spectrum allocation. In Section 4, we illustrate the market failures which require invervention by the government - the Tragedy of the Commons and non-competitive markets. In Section 5, we discuss different methods for assigning spectrum rights. In Section 6, we develop auction theory and evaluate auction designs based on theoretical and empirical results. In Section 7, we cover spectrum allocation in the context of the European Union. In Section 8, we present evidence from the United States spectrum auctions in support of centralized combinatorial auctions. We then recommend the the European Union use centralized combinatorial auctions to allocate spectrum licenses in Section 9. Finally, we conclude with an overview of our argument and recommendations for future research.

2 Background

In the following section, we provide fundamental information necessary to understand and appreciate the main discussion.

2.1 The Radio Spectrum

The radio spectrum (3 Hz-300 GHz) is the range of frequencies ideal for the transmission of data via electromagnetic waves[1]. Radio waves are used by AM and FM radio broadcasts, cordless phones, wireless networks, television broadcast, satellite communications, and ham radios. Each radio signal uses a different wave frequency in order to avoid interferance. Interferance occurs when two or more transmitters are using the same or similar frequencies. The radio waves then distort one another and the transmission becomes incoherent to the receiver. As technology has developed, transmitters have created less interferance, allowing more transmissions to be sent over similar frequencies without disruption. Theoretically, the spectrum is infinitely divisible and only the current level of technology prevents more users from transmitting radio waves without interference.

In discussing the European Third Generation (3G) auctions, we use the terms 3G and Universal Mobile Telecommunications System (UMTS) interchangeably[2]. These encompass more recent radio transmission technologies which use the radio frequencies from 1700 MHz to 2200 MHz, depending on local spectrum assignments. These high frequency transmissions are used in more elaborate personal communication devices, those capable of downloading music and using the internet. In discussing the United States auctions, we mention narrowband and broadband Personal Communications Services (PCS). Narrowband PCS is used for paging and data services. Broadband PCS is used for real time voice communication, such as in cellular phone services.

2.2 Auction Terminology and Design

Let us define some of the classical auction designs[3]. In an *ascending auction*, the price is successively raised until only one bidder remains, and that bidder wins the object at the final price. Such an auction can be run by having the seller or the bidders call out prices. In contrast, a *descending auction* works in exactly the opposite way – the auctioneer starts at a high price and slowly lowers it until a bidder calls out the current price and is awarded the object. In a *first-price sealed bid auction*, each bidder submits a single bid without seeing the bids of the other participants and the object is sold to the bidder who made the highest bid. The winner pays the price they bid. In a *second-price sealed bid-auction*, bidders again submit their bids secretly and the winner of the auction is the bidder with the highest bid. However, the winning bid buys the object at a price equal to the second highest submitted bid.

We say values are *private* in an auction if each bidder knows how much they value the object for sale and their value is independent of the values of the other bidders. We say values are *common* if the actual value of the object is the same for everyone but bidders have different, private information about what that value is. A bidder will then alter her behavior in an auction based on signals from other bidders. The *winner's curse* is a phenomenon in common-valued auctions whereby the winner of the auctions pays more on average than the object is worth and does not take into account the signals that come from other bidders dropping out out the auction.

A *simultaneous ascending auction* is such that the prices for several objects are raised concurrently until the price levels are such that the quantity demanded equals the quantity supplied. The winners of the objects are those bidders with the highest bids when supply and deman equilibrate. A *combinatorial auction* is such that the bidders compete for several goods and packages of those goods, the purpose being that if the objects are substitutes and complements for each other, bidders can optimize dynamically to new signals from other bidders and select the set of objects which maximizes expected value in any given round. The auctioneer selects winning bids that maximize total value amongst all possible packages. Both of these are types of *multi-unit auctions*, auctions where multiple goods are sold are the same time.

When we discuss *efficiency*, we are concerned with it in two contexts. First, there is the efficiency of an allocation mechanism which is measure by how well it assigns an object to the player with the highest value or expected value. Secondly, we are concerned with allocative and productive efficiency in markets, that is, efficiency in a post-assignment context. The term is used interchangeably and at times refers to both contexts.

3 Previous Literature

We begin with a review of the literature relevant to our topic. We first address the development of auction theory and then follow with a discussion of policy papers regarding the allocation of spectrum licenses both in the United States and the European Union.

Vickrey (1961) is regarded as the seminal developer of auction theory[4]. He develops special cases of the Revenue Equivalence Theorem, showing that several auctions all generate the same expected revenue. Roughly simultaneously, Myerson (1981) and Riley and Samuelson (1981) showed that Vickrey's result about the equivalence of expected revenue generalizes further, applying to both private-valued and common-valued auctions provided that the object always goes to the highest bidder and the bidder with the lowest signal expects zero surplus (thus applying to all of our classical designs mentioned above)[5][6].

Regarding multi-unit auction, Wilson (1979) demonstrates that in a uniform price auction, there are Nash equilibria that appear very collusive since they support prices that would be much lower than if the object were sold as an indivisible unit[7]. Bidders can implicitly agree to divide up the object at a low price by each bidding aggressively for smaller quantities than their equilibrium share, thus deterring others from bidding more. This is a consequence of the common-value nature of the model he uses. However, in a large class of of multi-unit auctions, it is difficult to achieve efficient outcomes, particularly if goods are heterogeneous, as shown by Jehiel and Moldovanu (2001)[8].

Bulow and Klemperer (1994) use the Revenue Equivalence Theorem to show that, in the case of homogenous good multi-unit auctions in which each bidder wants only a single unit, the expected revenue would be the same if the items were sold simultaneously or sequentially[9]. Also, Bulow and Klemperer (1996) show that when bidders' values and strategies are symmetric, the contribution of an additional bidder is worth more to the auctioneer in an ascending auction than the ability to set a reserve price[10].

They demonstrate that, very generally in private valued-auctions and a wide variety of common-valued auctions, a simple ascending auction with no reserve price and $N+1$ symmetric bidders is more profitable than any auction that can be realistically operated with only N bidders. Thus it is generally more worthwhile for the auctioneer to devote resources in attracting more bidders than to collect information on bidder values and setting a reserve price to reflect those values.

Coase (1959) is one of the earliest advocates of using a price-based mechanism to allocate spectrum licenses[11]. Coase writes in support of the assignment of spectrum rights by the U.S. government to those willing to pay the most for them, suggesting that the Federal Communications Commission (FCC) has thus far failed to define these rights sufficiently well. He argues that the system by which the government allocates licenses via comparative hearings gives rise to non-competitive markets, likening the licenses to subsidies which permit otherwise innefficient firms to operate unchecked. Firms must appeal to capital markets and demonstrate the expected value of their business plans if they are to be awarded a license, specifically by paying for the license rather than lobbying the FCC.

The key support for the use of spectrum auctions in the U.S. came from Kwerel and Felker (1985)[12]. They list the goals of spectrum assignment as being economic efficiency, fairness, and revenue for the public. Kwerel and Felker argue that auctions maximize benefits to consumers by assigning liceneses to the parties that value them most highly, thus fostering efficient spectrum use and minimizing wasteful private expenditures for obtaining licenses through comparative hearings. Further, auctions with well enforced rules are perceived as fair, objective, and transparent in comparison to comparative hearings. Finally, auctions may potentially raise large sums of revenue for the government, a politically appealling attribute.

McMillan (1994, 1995) provides a detailed argument for the use of auctions in the allocation of spectrum as well as an overview of the methodology and design of the 1994

US spectrum auctions [13] [14]. McMillan, one of the chief advisors to the FCC during the 1994 auctions, argues that auctioning licenses offers two advantages over lotteries and comparative hearings: 1) it raises revenue for the government and 2) it identifies those firms with the highest values for the spectrum. He argues that the FCC's use of a simultaneous multi-round and combinatorial auctions over a simple sequence of single-round sealed bid auctions was a triumph for not only public policy but also for game theoy.

While the reform of the U.S. spectrum allocation policies in 1993 addressed several of the critiques associated with lotteries and comparative hearings, Hazlett (2003) argues that further reforms are needed in order to realize the full potential of the spectrum auctions. He concludes that in order to establish an efficient secondary market for licenses, licenses should permit the owners to make use of adjacent buffer zones, spectrum must be exhaustively allocated, and allow owners to use their spectrum in anyway they see fit rather than being restricted to particular industries. Hazlett points out that auctions are the preferable method for initially assigning property rights but that it should be clear that revenue generation is not the purpose of these auctions. Many of his arguments are an elaboration of the *Comments by Thirty Seven Concerned Economists* and address the secondary market, not the initial allocation mechanism[15].

Spicer (1996) presents a survey of international spectrum assignment policies on behalf of the FCC[16]. He focuses solely on those nations which use auction mechanism to allocate spectrum licenses and draws comparisons between the United States and several other nations, concluding that the U.S. mechanism is the most successful. Spicer argues that in order to be successful, any assignment method must be transparent, encourage qualified participation, support sub-national licensing, sell similar licenses concurrently, clearly outline the rights and responsibilities of all participants, and make large numbers of licenses available. The U.S. auctions satisfice all of these criteria.

The Swiss 3G auction failure was 'caused by a combination of unfortunate events and bad auction design,' argues Wolfstetter (2001)[17]. He focuses on the Swiss government's inability to attract participants in the auction, largely a consequence of the auction design. Because the Swiss auction was scheduled later in the overall series of European 3G auctions, at the time it was conducted, it was already well known which firms would be dominant bidders. Thus, the auction attracted exactly as many participants as there were licenses and government revenues were trivial. Of particular relevance is Wolstetter's conclusion that a simple way to radically solve the bidder paricipation problem would be to auction the radio spectrum available for all users in a single auction. This would increase competitors by drawing firms not only from the telecommunications industry, but from satellite broadcasting and mobile communications as well. He contrasts these results with the success of the German auction in Wolfstetter, Grimm, and Riedel (2001)[18].

Drawing on the results of the European 3G auctions, Jehiel and Moldavanu (2002) argue that, since the main goal of most spectrum allocation procedures is economic efficiency, and since consumers do not participate at the auction stage, good auction designs must alleviate the asymmetry among incumbents and potential entrants by actively encouraging entry[19]. Entering the market by directly outbidding incumbents can be quite difficult unless new entrants are much more efficient and thus expect higher profits. If potential new entrants perceive that they are at a disadvantage, they will either not bother to bid or form consortia with incumbents. The authors point out that in a number of the 3G auctions, the number of licenses was set equal to the number of incumbents, thus making the entry of a new firm in domestic telecommunications market highly unlikely. However, even scenarios in which there were more licenses available than incumbents, poor auction design led to highly inefficient outcomes.

In their discussion of the British 3G auction (which they helped design), Binmore and Klemperer (2002) evaluate the outcome of the British auction and account for its high level of success in comparison with other European 3G auctions[20]. They suggest that the goal of any spectrum auction is to assign rights efficiently, promote competition, and, subject to the other objectives, realize the full economic value to consumers, industry, and taxpayers. The British government ultimately employed a simultaneous ascending auction for five licenses in a market with four incumbents, restricting each firm to winning only a single license. This auction structure combined with the government's ability to attract bidders, the dotcom bubble, and Britain's primacy in the European auctions accounted for its success in raising revenue and attracting new entrants. In a related paper, Klemperer (2002) emphasizes the role of sequencing in the success of the British and German 3G auctions – the sequence of the auctions affects how well bidders know how to 'play the game,' allows bidders to learn each other's valuations, affects complementarities, and alters how a firm is perceived in capital markets[21].

We have not uncovered literature which specifically argues for the centralization of European spectrum auctions, which we suggest is an improvement over the current allocative institutions in place.

4 Market Failure

In the following section, we develop and apply models of market failure to the use of radio frequencies by telecommunication firms and to the market for telecommunication services. We begin by addressing the tragedy of the commons which ensues when the state fails to assign and enforce property rights for the radio spectrum. We then address the welfare loss associated with the non-competive structure of the market for wireless communications and data transmission.

4.1 The Tragedy of the Commons

We begin with an illustration of the Tragedy of the Commons applied to the unrestricted use of the radio spectrum[22]. Let V be the value of the radio spectrum per transmission, T be the number of transmissions, and N be the the total number of transmitters, with $V = V(T, N)$. As the number of transmissions increase, the value of each transmission is eventually strictly decreasing and approaches 0, given the increase in interferences which is caused by an increase in unrestricted transmissions. Thus, we may assume that $\forall\ T \geq T^*$, $\frac{dV}{dT} < 0$, $\exists\ a > T^*$ such that $\lim_{T \to\ a} V(T, N) = 0$. For simplicity, we assume the transmitters have identical, linear value functions in the form $V = \alpha - \beta \sum_{i=1}^{N} T_i$, $1 \leq j \leq N$, $\alpha, \beta > 0$, however our result holds for more general average value functions provided our first two assumptions hold. Thus, the jth transmitter is faced with the problem of selecting how many transmission they should send in order to maximize their total welfare,

$$\max_{T_j} [VT_j] = \max_{T_j} \left[\alpha - \beta \sum_{i=1}^{N} T_i \right] T_j.$$

Solving, we have $VT_j = \frac{\alpha^2}{\beta(N+1)^2}$. Thus, as the number of entrants $N \to \infty$, the social welfare, $V \sum_{i=1}^{N} T_j \to 0$.

This suggests that we can improve social welfare by restricting private use of the radio spectrum. Indeed, if transmitters cooperate in order to maximize social welfare rather than individual welfare, we have $VT^* = \frac{\alpha^2}{4\beta}$. Note that this outcome is achieved if the transmitters behave as a single agent, $N = 1$, for the good of all. Under this scenario, each transmitter realizes a private welfare of

$$VT_j^* = \frac{\alpha^2}{4\beta N} > \frac{\alpha^2}{\beta(N+1)^2} \quad \forall N > 1.$$

However, without enforcement each firm has an incentive to deviate from this social welfare maximizing strategy. Thus any institution which restricts use of the spectrum to the socially optimal quantity and enforces these restrictions would provide a Pareto improvement. The state may efficiently assign property rights to bandwidths of the radio spectrum in order to prevent the Tragedy of the Commons; the sum of the bandwidths of the spectrum licenses would equal the socially optimal quantity with each bandwidth in a region being owned by exactly one firm [23]. Since this is a feasible sollution, we conclude that the state should intervene and assign spectrum rights in order to maximize social welfare.

4.2 Oligopolistic Markets

The market for telecommunications services is non-competitive to the detriment of society as a whole[24]. Many firms have long enjoyed favoritist and protectionist policies from the government and now have a tremendous advantage over new entrants, to the point of excluding entry altogether in some markets[2]. Using a standard Cournot model of oligopoly, we shall illustrate that as the number of firms in a market increases, so does social welfare[25]. Let P be the price of telecommunications services, Q_m be the market quantity, N be the total number of firms in the market, C_i be the ith firm's cost function, and π_i be the ith firm's profit function, $1 \leq i \leq N$. Again, in order to provide a simple illustration, we shall assume constant symmetric marginal costs for all firms and that the inverse demand function is linear and in the form $P = \gamma - \delta Q_m$, $\gamma, \delta > 0$; however our results hold for a much wider range of profit and demand functions. Thus, each firm i is faced with selecting the quantity to produce in order to maximize profit,

$$\max_{Q_i} \pi_i = \max_{Q_i} PQ_i - CQ_i = \max_{Q_i} \left(\gamma - \delta \sum_{i=1}^{N} Q_i \right) Q_i - CQ_i.$$

Solving for the profit maximixing quantity, we have $Q_i^* = \frac{\gamma - C}{\delta(N+1)}$. Thus, for N firms in the market, the social welfare is

$$\int_0^{Q_m^*} [(\gamma - \delta Q_m) - C] \, dQ_m = \gamma \frac{N(\gamma - C)}{\delta(N+1)} - \frac{\delta}{2} \left(\frac{N(\gamma - C)}{\delta(N+1)} \right)^2 - C \frac{N(\gamma - C)}{\delta(N+1)}.$$

[2]In Germany, the dominant telecommunications firm, Deutsch Telecom, is still majority owned by the government despite a general trend towards liberalization in the European Union market. It has served as a dispenser of state policy, as we discuss later.

Since social welfare is eventually monotonic in N, this suggests that we can increase social welfare by increasing the number of firms participating in the market, coinciding with our intuition. Thus, as the state asigns spectrum rights, any mechanism by which it does so that also encourages entry into the telecommunications market is desirable. We shall keep this in mind as we examine our options for efficient spectrum allocation.

5 Allocation Methods

We now address three possible options for allocating spectrum rights: comparative hearings, lotteries, and auctions. Each is evaluated using both theoretical and empirical results with regards to its ability to assign licenses efficiently.

Comparative hearings, which are still widely used throughought the world, are useful for their political flexibility. The government can impose any criteria it chooses and thus use the allocation to address specific policy goals. For example, the hearing processes used in Canada have been described by the government as being ideal for guaranteeing the best fit for the mobile communications market by comparing a firm's proposal against well developed criteria [14]. However, the participants in the hearings have described the auctions in the opposite manner, stating that the criteria are vague and the weight each is given is not well-defined. When hearings were still used in the U.S., Glen O. Robinson, a former member of the FCC, described the hearings as 'the FCC's equivalent of trial by ordeal.'[3] Overall, it is difficult to specify and evaluate criteria for allocation via comparative hearings. They are time-consuming and opaque processes that lead to political and legal controversy and the perception, and perhaps the reality, of favoritism and corruption. As Binmore and Klemperer point out, some governments make no secret of selecting comparative hearings as their prefered means of allocation specifically because of the opportunities for favoring national champions over

[3]Quoted in McMillan (1995).

foreign firms[20]. Incumbent firms that have accumulated experience in comparative hearings enjoy an advantage over new entrants; such firms often argue that their pre-existing infrastructure provides them with an advantage in providing services beneficial to society. We thus reject comparative hearing as an efficient means of allocating spectrum rights since it is both costly and systematically favors incumbent firms.

Starting in 1982, the U.S. began using lotteries to allocate spectrum licenses to address the significant backlog of license applications. A Coasian argument was made in favor of lotteries – even if licenses were initially misallocated, the secondary market would ensure that those licenses would eventually find their way to those who valued them most. However, the Myerson-Satterthwaite theorem shows that no feasible bargaining protocol can guarantee an efficient outcome [26]. Empirical evidence also suggests that lotteries are not the most efficient choice for assigning spectrum rights. In the U.S., nearly 400,000 applications were recieved for the lotteries, many of which from individuals who lacked any technical expertise in radio communications[14]. While resale of the licenses may eventually correct initial misallocations, this comes with costs in the form of delayed services provided for customers and resources spent on searching and transactions. Thus, we also reject lotteries for allocating spectrum rights since it generates windfalls, delays, and forces firms to engage in costly transactions in the secondary market.

We are left with auctions. By their very definition, auctions allocate licenses to those firms that value them most. These firms are generally able to provide consumers with the services they want most efficiently. Also, auctions provide the government with information about the value of the licenses for future allocations[27]. Auctions also eliminate wasteful private expenditures for obtaining licenses. Under comparative hearings, firms expend resources to increase their probability of winning a license, a process which dissipates much of the economic profit these firms would otherwise allocate to dynamically efficient processes. A well designed auction increases competition in the telecommunications market – the state is no longer able to grant special privileges to the well connected. Provided capital markets are working efficiently, entry into the telecommunications market should be significantly easier via auctions.

However, some critics argue that auctions are not the Holy Grail so many economists make them out to be[28]. Common arguments against auctions include: 1) auctions raise the price of telecommunications services, 2) auctions reduce the winning firm's investment, 3) auctions lead to a monopolization of the spectrum, 4) and small businesses are unable to compete in the auctions. However, these arguments are largely misconceptions. The cost of winning at an auction has no effect on the price customers pay for a service – such an expenditure is a sunk cost. Similarly, auctions do not reduce the winning firm's investment. Once licenses are aquired, the decisions for how and when to go forward with investment depends on expected revenues and costs. If firms are permitted to resell their licenses, the risk of monopoly is no greater under auctions than under comparative hearings or lottery. Finally, provided capital markets are working efficiently, small businesses can raise sufficient funds to compete in an auction against incumbents. However, since this hypothesis is rarely if ever fulfilled, governments can provide certain handicaps to create a more equitable auction environment[4] [20]. Thus, we can conclude that auctions are the preferable mechanism for assigning spectrum rights. Indeed, auctions are now the mechanism of choice by nations such as Great Britain, the United States, Great Britain, and Australia for assigning spectrum rights.

6 Auction Design

Now that we have settled on auctions to assign property rights, we must consider what format of auction is to be used. Were we to consider only the welfare of the firms that participate in a spectrum auction, it would be sufficient to assign licenses

[4]The FCC has a Designated Entities rule whereby small firms that are minority owned are given a bidding handicap ranging from 5-20 percent.

to those firms that are willing to pay the most in any auction format since, by the Revenue Equivalence Theorem, the winner of the auctions will, on average, be the firm that values the licenses the most. However, there is also a post-assignment factor which must be considered in the maximization of welfare: the competitive nature of the market. Thus, we must select an auction design which 1) assigns licenses to those firms that value them the most and 2) encourages participation and new entry into the telecommunications market. Much of our analysis of auction design is drawn from Milgrom (2004), one of the designers of the US auction mechanisms[29].

First, we acknowledge that since we are allocating several (possibly several hundred) licenses, it is better to run an auction which awards many licenses simultaneously rather than one license at a time. Assigning licenses sequentially consumes valuable time and distorts the strategies of early and late auction participants. Consider the conjecture that the value of licenses are related; they can be substitutes and complements for one another. In its simplest cases, two licenses for the same frequency in neighboring geographic regions would be complements, while two licenses for the same geographic region on different frequencies would be substitutes. Thus, if an early bidder fails to aquire a complementary license in an early round, they might be discouraged from participation in later rounds. Thus, the auction draws fewer bidders overall, attracting fewer new entrants to the market. So we discuss only multi-unit auctions.

There are three primary models of multi-unit auctions from which we can select. First, we consider the simultaneous ascending, homogenous goods auction. Then, we evaluate the simultaneous ascending, heterogenous goods model. Finally, we look at the combinatorial ascending auction, which we argue is the preferable auction design of these three.

In a simultaneous auction with homogeneous goods, an auctioneer offers bidders several similar goods with the hope of achieving an allocation at a uniform price. This is the auction style favored by most of the European countries during the 3G auctions.

Theoretically, such an auction can generate competitive bidding provided values are private and all goods are pure substitutes. However, such an auction risks demand reduction – a stable Nash equilibrium whereby bidders offer low bids which replicate collusive prices without actually colluding (see Figure 1). While this may still succeed at allocating licenses to those who value them most, such an outcome is politically embarrassing. Further, when homogenous licenses are offered, in order for bidding to be approximate efficiency, it is necessary that the licenses are truly pure substitutes for one another – this leaves us with offering mostly national or continental level licenses since regional licenses can be complements for one another. Such national level licenses tend to bias incumbents and exclude small businesses and new entrants from the bidding process.

In a simultaneous auction with heterogeneous goods, bidders are able to consider how different goods complement each other during the bidding process as well as select from a variety of choices to maximize their expected value. This is the design currently favored by the FCC. Such an auction is useful in that it allows firms to aggregate licenses. This allows the auctioneer to offer goods which are complements for each other and also divide the goods into segments with greater variety to appeal to a wider group of bidders. However, such an auction does not fully account for the effects of complements – in order to guarantee that the the maximum value of licenses is realized, it is necessary that firms are able to offer bids on entire packages rather than trying to build those packages piecemeal during the auction.

In a combinatorial auction, the bidder is faced with the decision of selecting amongst several heterogeneous and related goods and selecting the package of goods which maximizes their expected value. After each round of bidding, the auctioneer will notify the participants of the packages for which they are the highest bidder, allowing them to resubmit a bid if they are not currently the highest bidder on the package the most value. The auction ends after a round passes with no new bids. In a combinatorial auction, it is often the case that allocating the goods to the bidders with the highest values can result in non-competitive bidding, i.e., prices for which there is only one interested bidder (see Table 2 [30]. Since bidders may be vying for intersecting sets of licenses, it is possible for competition between two bidders on a single license to raise the high bid on a large package of several licenses. Of particular note is the case where a weak bidder is trying to enter the telecommunications market and values only a few licenses, while an incumbent bidder values a large aggregation of licenses. The new entrant is able to compete in the auction against the incumbents for those licenses that they both value. If only larger licenses were auctioned off, new entrants with regional aspirations may be discouraged from participating in the auction. The FCC is currently scheduled to use a combinatorial auction to allocate licenses, as we discuss below.

7 European Spectrum Allocation

In this section, we provide an overview of empirical evidence in support of the claim that the current means by which the member states of the European Union allocate spectrum licenses are sub-optimal. We discuss the European 3G allocations to support this claim.

Each member state has the right to allocate the spectrum however it sees fit on the condition that individual licenses are 'granted through open, non-discriminatory and transparent procedures with reasonable time limits.'[31] These requirements are generally open to interpretation, as seen in the European 3G allocations which took place from March 2000 to September 2001. The allocation mechanisms varied between countries. Even those countries which used the same mechanism, such as an auction, implemented diverse rules which resulted in divergent outcomes. Revenue ranged from as high as EUR 650 per capita in Britain to EUR 20 per capita in Switzerland (see Table 3). While most countries gained a new entrant, some of the auctions generated highly non-competitive markets. What accounts for such variable and discouraging results? We contend that failure to attract bidders, poor auction design, sequencing, collusion, and an inability to commit to auction outcomes all combined to induce an inefficient outcome.

The British government worked to ensure that their auction would be the first in the EU. It originally planned to auction off four licenses, exactly as many as there were incumbent firms. In order to attract entry, Klemperer and Binmore designed a multi-stage hybrid auction in which the first stage would be conducted as a simultaneous ascending auction until there were only five bidders left, at which point each bidder would submit a sealed bid for the licenses to determine the winners[20]. No firm was allowed to aquire more than one license. The hope was that the sealed bid stage would introduce uncertainty about which four of the five finalists would win, attracting entrants that believed they had a chance to make it to the final round and outbid a stronger opponent. However, it eventually became possible for five licenses to be sold, at which point the auction designers opted for a simple simultaneous ascending design with near-homogenous licenses. The guarantee that at least one license had to go to a new entrant was sufficient to attract nine new entrants. Britain's position as the first auctioneer gave them a distinct advantage; there was sufficient uncertainty between competing bidders to encourage entry and competitive bidding. The auction designers were keenly aware of the importance of attracting entry and planned accordingly. The British auction raised the greatest revenue of the European 3G auctions, bringing in EUR 650 per capita.

On the heals of the British auction came the Dutch blunder of offering five licenses when there were only five incumbents through an ascending simultaneous auction[21]. Very few entrants showed up to the auction as they recognized their weak bidding positions. Further, the Dutch competition policy was sufficiently weak that local incumbents were allowed to partner with large international firms. Of particular note was the position of the weak incumbent Ben which, after a partnership with Deutsche Telecom, was able to position itself as a strong bidder and discourage collusion. Revenues fell far short of projections by 70 percent, suggesting that there may have been a more efficient allocation of the licenses to firms with a higher value.

The Italian auction offered five licences in a market with only four incumbents, so a new entrant was guaranteed. They also opted for an ascending simultaneous auction similar to Britain's. The Italian government had reserved the right to decrease the number of licenses offered on auction day if fewer bidders shoed up than licenses. Although six bidders originally showed up, after only 11 rounds, one firm, Blu, dropped out. The remaining five firms paid EUR 2.4 billion per license, grossly missing forcasts. The auction's outcome was only recently finalized following accusations by the government that Blu's participation in the first place was a consequence of collusion and that they were never a serious bidder[8].

Germany enjoyed the most successful auction following Britain's. They favored a multistage combinatorial auction in which bidders could aggregate licenses, subject to some restrictions, and bid for the package which maximized their expected value. This modification worked to the government's advantage. The government ended up with high revenues, generating approximately 94 percent of the British revenue per capita and created an unconcentrated market with six bidders each winning two of twelve blocks of licenses[21]. The combinatorial auction brought in two new entrants and generated sufficient uncertainty in the outcome to encourage competitive bidding. However, we should note that there was suspicion surrounding the behavior of the government controlled firm Deutsche Telecom which appeared to push price levels far above those that weaker firms had demonstrated themselves willing to pay.

The literature widely regards the Swiss auction as being the greatest blunder of the 3G auctions. They opted for the British design of a simultaneous ascending auction with nearly uniform licenses. Aside from the government raising the least revenue per capita of all the countries which auctioned spectrum rights, the government attempted to renege on the auction rules when only four firms showed up to bid for the four licenses offered [17]. The licenses were awarded to three bidders at CHF 50 million and one bidder, Orange, at CHF 55 million. Orange paid the extra CHF 5 million to ensure that it aquired the license to a frequency it had already won in a neighboring country. The lone new entrant, Telefonica, had already aquired 3G licenses in Spain, Britain, and Germany, thus establishing itself as a multinational service provider. The behavior of these two firms is worth noting – their strategies in the Swiss auction were largely influenced by their gains from earlier auctions.

Austrian auction followed the German design [21]. It failed to attain anything close to the level of success of the German auction in generating revenue. The government set the reserve price very low and only six bidders showed up for twelve blocks of licenses. With so few bidders, it was easy for firms to collude to end bidding early on and guarantee each firm two blocks each. While two new entrants were given access to the Austrian market, with such non-competitive bidding, it is questionable as to whether or not these firms were those which most valued the spectrum rights. Furthermore, having demonstrated a willingness to collude in the auction, there is reason to believe these firms may collude in the 3G services market to the expense of consumers.

Klemperer attributes the variation in the European auctions to the affect of sequencing [21]. In early auctions, firms face uncertainty regarding their opponents' bidding strategies and expected values. This uncertainty motivates weaker firms to participate in the auctions, believing they have some non-trivial probabilty of winning, and stronger firms to place higher bids, as they are unsure of their opponents' willingness to pay. Further, Klemperer argues that with each auction, firms learned how to 'play the game' better. Note that Italy, the Netherlands, and Switzerland, which all implemented a design similar to the British, had much lower per capita revenue than Britain. When Germany changed the auction format, we observed another large spike in revenue which quickly tapered in subsequent auctions of the similar design.

Also, complementarities played a large role in deciding which firms participated in later auctions. Licenses that were auctioned later were more valuable to winners from earlier auctions if the new licenses fit into their overall network. Radio waves do not travel according to the arbitrary boundaries on licenses; firms can use their established infrastructures in neighboring countries to reinforce each other. This creates a disincentive for firms that were unable to aquire key licenses of multinational networks from participating in future auctions. Thus, we must address the sequencing of the European auctions if we are to generate more efficient outcomes.

In contrast to the EU, the United States has effectively dealt with the issues surrounding sequencing by selling all similar licenses in a single auction, alternating between combinatorial and simultaneous ascending auctions as the case warranted. The European Union could enjoy a potential Pareto improvement if they followed suit.

8 Lessons from the FCC

The United States led the way in liberalizing the allocation of spectrum licenses through efficient auction design. The FCC administers simultaneous, multi-round auctions. They have been highly successful since their inception in 1994. In this section, we draw on evidence from the US auctions in support of our claim that centralized, combinatorial auctions can lead to efficient outcomes. We will focus primarily on their 1994-1996 auctions to illustrate their pragmatic designs.

The FCC followed the recommendations of its theorists and opted for an open auction rather than a single-round, sealed-bid auction, the advantage being that an open auction decreased the chances of a winner's curse[29]. With billions of dollars at stake, it was important that the auction bring together all of the firms' information on the value of the licenses so as to avoid sub-optimal outcomes. While the FCC was also wary of collusion that often results from an open bidding process, it decided that the value of avoiding the winner's curse outweighed the risk of collusion[5]. In order to control information better, the government opted to run the auction in multiple rounds of sealed bidding, anouncing the highest bidder only at the end of each round.

The government also favors simultaneous and combinatoric auctions with heterogeneous licenses over sequential auctions of homogenous licenses. This is a response to the speed with which a simultaneous auction can conclude with the added advantage that they allow bidders to aggregate sets of licenses to optimize their expected value rather than being stuck with government-determined license regions. The FCC also assigned Designated Entities, whereby minority owned firms and small businesses were awarded a bidding handicap. This attracted new entrants and helped promote competitive bidding processes.

In his evaluation of the auctions, Cramton (1997) judges them to be a success, both in their efficiency and in their verification of auction theory [32]. Similar licenses sold for similar prices and bidders appeared to form efficient aggregations of licenses. The FCC started with the simplest auctions, offering ten nationwide narrowband PCS licenses. The auction lasted for 47 rounds and raises USD 617 million. Aggressive, competitive bidding was observed amongst all participants. As the auctions progressed, more complicated aggregations were possible. FCC Auction 2 offered 30 regional narrowband licenses; prices were 12.4 percent higher per capita than in the nationwide auctions, demonstrating that offering more choices incited firms to compete for licenses of overlapping interest. In the third auction, the FCC offered two broadband PCS licenses for each of 51 regions. Bidding was much more cautious in this auction – raises and activity were at much lower levels and the auction lasted much longer, 112 rounds!

[5] In later auctions, firms were caught signaling to each other by ending their bids with the zip-codes associated with the licenses they desired in order to generate non-competitive outcomes. Recently, the FCC has restricted the bids such that they can only be made in rounded increments, e.g. USD 100,000 units.

The FCC was able to raise USD 7.7 billion between the 18 winning firms (out of 30 initial participants). In the second broadband auction, the bidding went 184 rounds for 493 seperate regional licenses, raising USD 10.2 billion. In the final two auctions, the FCC offered wireless broadcasting licenses for regions that were not currently assigned to one of the incumbents – substantial holes existed where the FCC had previously awarded licences through comparative hearings. Not surprisingly most of these went to incumbents that, because of a strong complementarity effect, had a greater incentive to aquire the licenses over new entrants.

In contrast to the European 3G auctions, the revenue generated exceeded expectations in all FCC auctions. Further, the FCC auctions received highly favorable reviews from participating firms. These results give us reason to conclude that this sort of weak combinatorial auction encourages competitive bidding and the efficient allocation of resources. Firms were able to consider the behavior of their competitors during the auction without any firm revealing their strategies from earlier auctions, since the licenses offered in each auction had different engineering traits. Collusion was avoided thanks to the high number of bidders and the telecommunications market gained several new entrants. We believe this also provides support for the theoretical results that a pure combinatorial auction would generate a superior outcome.

The combinatorial FCC Auction 31, which will allocate spectrum licenses for the 700 MHz bandwidth, permits bids on on any of 4095 possible packages. The FCC tested an early version of the design in laboratory experiments. While the bidders required more training and the auction took longer to conclude than simpler FCC designs, it was found that on average, the complex package design led to more efficient outcomes[33]. However, this auction was postponed to collect further feedback and is currently scheduled to begin on January 24, 2008. We await its outcome to further weigh our claims.

9 Recommendations

We recommend that the European Union allocate spectrum licenses through a centralized, combinatorial auction. A centralized auction is advantageous since it eliminates the anomolies associated with the sequencing of auctions in individual nations. If all licenses of a type for the entirety of the continent are auctioned off at once, winners will not provide information regarding their bidding strength to competing firms. This will attract entrants that would otherwise be discouraged if earlier auctions had revealed that strong and incumbent firms would be bidding aggressively, making the perceived probability of an entrant winning a license trivial. As an additional benefit, by centrally allocating licenses, firms will enjoy consistent allocation rules, reducing their need to employ specialist techniques in each member state for aquiring licenses, e.g., developing different bidding strategies for different auctions or devoting resources to the aquisition of licenses through comparative hearings.

A combinatorial auction will allow firms to optimize dynamically through the course of the auction, select license packages best suited to promote their comparative advantages, and encourage more competitive bidding. Firms would be able to select packages of licenses, accounting for complementarities and substitutes. While combinatorial auctions can be complex when the number of licenses becomes large, we believe that sub-optimal outcomes may be minimized by providing bidders with sufficient time to learn the rules of the auction and analyze their choice set and expected values. Combinatorial auctions would allow bidders to build national license packages or concentrate in specific geographic markets. This would create competition between large multinational telecommunications companies and local telecommunications firms, generating higher revenue by discouraging collusion.

10 Conclusion

In an unregulated market, radio spectrum is overused and interference prevents anyone from realizing the full value of transmissions. In order to alleviate this Tragedy of the Commons, the state should intervene and restrict the spectrum that may be used and assign and enforce property rights to the spectrum. However, because the market for telecommunications service is non-competitive in many nations, it is important that the government assign these property rights in such a way as to promote a competitive market to maximize social welfare. There are a few options for allocating the spectrum: first-come first-serve, comparative hearings, lotteries and auctions. Of these mechanism, auctions are the most efficient and socially desirable. Although complex, of the auction formats studied, a combinatorial auction provides several key advantages over others in encouraging efficient allocations, permitting new entrants, and allowing bidders to optimize dynamically. Evidence from the 3G license allocations in Europe suggest that further inefficencies may be avoided by auctioning all licenses for the continent simultaneously rather than in sequence. This evidence is supported by the results of the U.S. spectrum auctions. Thus, it would be in the interest of the citizenry of the European Unions of allocate spectrum licenses through a single, centralized combinatorial auction.

Further research is needed to determine the robustness of combinatorial auctions in generating competitive bidding so that we can better understand their limitations and attempt to appropriately design them. Also, if combinatorial auctions are to be made efficient, it is necessary to develop superior techniques for optimizing large scale combinatoric problems under uncertainty; currently such problems are mathematically intractable on large scales.

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A Diagrams, Tables, and Figures

This section includes supplementary information to illustrate key ideas for the reader.

		Bidder 1	
		Bid on License A	Bid on License B
Bidder 2	Bid on License A	5,5	10,10
	Bid on License B	10,10	5,5

Table 1: Demand Reduction in a Two-Bidder Simultaneous Auction for Homogeneous Goods

Here, we have two identical bidders competing for two identical licenses in an auction. In such a scenario, the bidders would prefer to obtain licenses at the lowest possible cost. If each firm tries to aquire both licenses, they must compete against each other and risk a lower payoff. However, each may reduce their demand and bid on only a single license, in which case they may avoid driving up the prices on the licenses and realize a higher value. This is similar to case of oligopsony in which firms reduce their demand for a production input without colluding to do so.

	Package						
Bidder	**A**	**B**	**C**	**AB**	**BC**	**CA**	**ABC**
1	3	3	0	30	3	3	30
2	0	3	3	3	30	3	30
3	3	0	3	3	3	30	30
4	3	3	3	24	24	24	**36**

Table 2: Bidder Values with Strong Complementarities without Competitive Prices [30]

Here, there are three small bidders: Bidder 1 who is interested in license A and B, Bidder 2 who is interested in B and C, and Bidder 3 who is interested in A and C. These can each be thought of as bidders interested in competing in regional telecommunications markets. Bidder 4 can be though of as a national level bidder who is interested in all three licenses. Bidder 4's value of 36 for package ABC produces the maximum efficiency in this example. In a simultaneous auction for heterogeneous goods, any allocation would be inefficient since Bidder 4 could never be the simultaneously high bidder on licenses A, B, and C, and the second best scenario would involve, without loss of generality, Bidder 1 winning licenses A and B and either Bidder 2, 3 or 4 winning license C, realizing a combined value of 33. Thus, a combinatorial auction would be preferable in such a case of strong complementarities.

Country	**EUR per Capita**	**Date**
Great Britain	650	March-April 2000
The Netherlands	170	July 2000
Germany	615	July-August 2000
Italy	240	October 2000
Austria	100	November 2000
Switzerland	20	November-December 2000
Belgium	45	March 2001
Greece	45	July 2001
Denmark	95	September 2001

Table 3: Revenues of the European 3G Auctions[21]