Auction Theory and Implementation: The Case of Telecom Licenses

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1 Introduction

It is often challenging for sellers of goods to identify the willingness to pay of potential buyers. One solution is to simply state a "take-it-or-leave-it" offer. This pricing strategy may or may not extract the maximum amount of surplus that the seller hopes to obtain. An auction is an economic mechanism that bypasses this problem by revealing the true valuations of the potential buyers. There are several types of auctions and each is defined by a set of rules for how the auction will operate. Today, auctions are used in many different areas including the energy and financial asset markets, and more recently, the allocation of segments of the radio spectrum to mobile phone companies. Analysis of these and other types of auctions have shown that design and implementation are crucial in determining the success of an auction.

One of the most interesting characteristics of auctions is that one can study them both on a theoretical and empirical level because the rules are very well defined. Thus this paper will proceed as follows. Section 2 outlines the background on auction theory in general terms with primary reference to the paper by Wolfstetter [8]. This includes a brief look at the various types of auctions and the predictions that have resulted from the theory. Also discussed are the various failures in auctions including collusion among bidders, design problems, and predatory bids. Then in section 3, the analysis turns to the specific case of auctions with imperfect information with reference to the paper by Hendricks and Porter [3]. The theory is developed to determine optimal bidding strategies and resulting payoffs, and then the empirical results are examined to test the theory.

In section 4 of the paper, building on the model of asymmetric information, the 2000 auction for third generation telecommunication licenses in the United Kingdom is examined. This historic auction generated an impressive 22.5 billion pounds and has been reproduced in other parts of the world due to its astounding success. Following the papers by Binmore [1] and Klemperer [4], the implementation of the auction and the bidding strategies of the 13 participating firms will be considered. The information asymmetry studied in Hendricks and Porter has similar effects to the cost asymmetries among the bidders in the telecom auction. Finally, with reference to the Borgers and Dustmann article [2], the way in which firms form their valuations and bids in the 3G auction is examined. The rationality of this behavior is considered and possible explanations are put forward to explain the discrepancies. Section 5 concludes.

2 Auction Background

The most common types of auctions are the Dutch and English, but many variations of these two are possible. More broadly, auctions can be separated into either oral or written. A Dutch oral auction is also referred to as a first price descending clock auction. The auctioneer starts the price at some high level and gradually lowers the price until the first person commits to buying the item at the price shown. In a written or sealed bid Dutch auction, the participants make private bids for the item and the winner, the highest bidder, pays her bid. In an oral English auction, the bidding starts low and rises until only one bidder remains. Finally, in a sealed bid English auction, the highest bidder again wins the item, but only has to pay the second highest bid.

Beyond English and Dutch auctions, there are several other classes of auctions. Charity or "all-pay" auctions involve every participant paying her bid no matter if she has won the item or not. There are also multi-unit auctions where participants bid for many items at once. This type is similar to the telecom license auction, which will be discussed later. The somewhat surprising result of all the various types is that auctions that award the item to the highest bidder and have the same levels of participation, will result in the same payoff to the seller independent of the specific rules of the auction [8]. This result is known more generally as the *Revenue Equivalence Theorem*, and the following example shows how the sealed bid versions of the English and Dutch auctions result in the same expected revenue for the seller.

2.1 The Revenue Equivalence Theorem: An Example

Before proceeding with the analysis of revenue equivalence, some notation needs to be introduced. Suppose there are $i = 1 \ldots I$ participants (players/bidders) in an auction, each with valuation θ_i. Bidder i bids some proportion α_i of his valuation, such that,

$$b_i = \alpha_i \theta_i \text{ for } \alpha_i \in (0,1). \tag{1}$$

Define the probability that bidder i wins the auction as y_i. Thus, assume bidder i has utility,

$$U_i(y_i, \theta_i) = \theta_i y_i - t_i, \tag{2}$$

where t_i is the payment that is made to the seller after winning the item.

Thus, first consider a Dutch auction, or a first price sealed bid auction. Suppose there are only two players or, $I = 2$. Allocation probabilities can be defined as follows:

$$y_i = \begin{cases} 1 & \text{if } b_i > b_j \; \forall \; i \neq j & \text{Implies } t_i = b_i \\ 0 & \text{if } b_i < Max\{b_j\} \; \forall \; j & \text{Implies } t_i = 0 \\ 1/2 & \text{if } b_i = b_j & \text{Implies } E[t_i] = b_i/2 \end{cases} \tag{3}$$

Note that when both players bid the same amount, assume the expected price paid is one half the bid. To take the final step, one more assumption is needed. Assume bidder's valuations are distributed, such that,

$$\theta_i \sim U[0,1]. \tag{4}$$

Noting that θ_1 is private information, player 1 determines his optimal bid by maximizing his expected gain:

$$\begin{aligned} & Max_{\{\alpha_1\}} && (\theta_1 - b_1) \cdot Prob(b_1 > b_2). \\ & \Leftrightarrow && \theta_1 - \alpha_1\theta_1 \cdot Prob(\alpha_1\theta_1 > \alpha_2\theta_2). \\ & \Leftrightarrow && \theta_1(1-\alpha_1) \cdot Prob(\alpha_2 < \frac{\alpha_1}{\alpha_2}\theta_1). \\ & \Leftrightarrow && \theta_1(1-\alpha_1) \cdot \frac{\alpha_1}{\alpha_2}\theta_1. \\ \frac{\partial}{\partial \alpha_1} \quad & \Rightarrow && 1 - 2\alpha_1 = 0 \Longrightarrow \alpha_1 = \frac{1}{2}. \end{aligned}$$

So the optimal strategy for player 1 in a Dutch auction (and symmetrically for player 2) is to bid one half of his valuation. At first glance this seems suboptimal because buyers are not reporting their true valuations.

Now consider a second price sealed bid auction or the English type. Here the allocation probabilities in a two player auction are as follows:

$$y_i = \begin{cases} 1 & \text{if } b_i > b_j \ \forall\, i \neq j & \text{Implies } t_i = b_j \\ 0 & \text{if } b_i < Max\{b_j\} \ \forall\, j & \text{Implies } t_i = 0 \\ 1/2 & \text{if } b_i = b_j & \text{Implies } E[t_i] = b_i/2 \end{cases} \tag{5}$$

Note the only difference is that if player 1 submits the highest bid and wins the auction, he only pays player 2's bid. Define the vector of *other* bids, b_{-i}, such that,

$$b_{-i} = (b_1, b_2, \ldots, b_{i-1}, b_{i+1}, \ldots, b_I). \tag{6}$$

Let b^*_{-i} be the maximum bid in b_{-i}, or from player i's perspective, b^*_{-i} is the highest competing bid. Now consider two cases.

- Assume $\theta_i \leq b^*_{-i}$. If player i bids anything below b^*_{-i}, his utility is 0 because he loses the auction. Note that this includes bidding $b_i = \theta_i$. Bidding $b_i \geq b^*_{-i}$ may result in him winning the auction, but his utility is $\theta_i - b^*_{-i} \leq 0$ because he pays the second highest bid. So in this case bidding $b_i \leq b^*_{-i}$ is bidder i's optimal reply.

- Assume $\theta_i > b^*_{-i}$. If player i bids anything below b^*_{-i}, his utility is 0 because he loses the auction. Bidding $b_i \in (b^*_{-i}, \theta_i]$ results in utility $\theta_i - b^*_{-i} > 0$. Bidding $b_i > \theta_i$ also results in utility $\theta_i - b^*_{-i} > 0$. So in this case bidding $b_i > b^*_{-i}$ is bidder i's optimal reply.

In both cases, the set of optimal replies for player i include bidding his valuation, θ_i. Thus $b_i = \theta_i$ is a Nash equilibrium strategy. In an English auction, the optimal strategy is for each player to bid their valuation.

So finally moving to the auctioneer's side, it is possible to calculate the expected revenue from each type of auction. The auctioneer's expected revenue in a first price auction from player 1 is calculated as follows:

$$\begin{aligned}
E[t_1(\theta_1)] &= E[b_1|\theta_2 < \theta_1]. \\
&= E[\frac{1}{2}\theta_1|\theta_2 < \theta_1]. \\
&= \int_0^1 \int_0^{\theta_1} \frac{\theta_1}{2} d\theta_1 d\theta_2 \\
&= \int_0^1 \frac{\theta_1}{2} \left(\int_0^{\theta_1} d\theta_2 \right) d\theta_1 \\
&= \int_0^1 \frac{\theta_1}{2} \theta_1 d\theta_1 \\
&= \int_0^1 \frac{\theta_1^2}{2} d\theta_1 \\
&= \frac{1}{6}
\end{aligned}$$

Equivalently, $E[t_2(\theta_2)] = \frac{1}{6}$, so the auctioneer's total expected revenue is $\frac{1}{3}$. In the second price auction, the auctioneer's expected revenue is calculated similarly:

$$\begin{aligned}
E[t_1(\theta_1)] &= E[b_1|\theta_2 < \theta_1]. \\
&= E[\theta_2|\theta_2 < \theta_1]. \\
&= \int_0^1 \left(\int_0^{\theta_1} \theta_2 d\theta_2 \right) d\theta_1 \\
&= \int_0^1 \frac{1}{2}\theta_1^2 d\theta_1 \\
&= \frac{1}{6}\theta_1^3 \Big]_0^1 = \frac{1}{6}
\end{aligned}$$

And again, an equivalent argument can be shown for player 2. Thus the auctioneer's total expected revenue in an English auction is also $\frac{1}{3}$. Hence the *Revenue Equivalence Theorem*. In the Dutch auction, even though players bid only one half of their valuation, the expected revenue from the auction is the same as in the English auction. This can be extended to auctions with more than two bidders. The result is that in an English auction, players should always bid their valuations, while in a Dutch auction, the optimal bid increases from $\frac{1}{2}\theta$ up to θ as the number of players rise [6].

2.2 Auction Failures and the Winner's Curse

Though it has been shown that auctions can be used to get around the problem of buyers not revealing their true valuations, they are subject to a variety of other problems. The most obvious problem is collusion. Particularly in oral auctions, it is difficult for a seller to stop buyers from colluding to bid low for an item. In a multi-unit auction, buyers can use the early stages of the auction to signal other buyers which items they are most interested in, and thereby keep the winning bid lower than it would be otherwise [4]. Repeated or multi-round auctions are relatively more prone to collusive behavior because there are more opportunities for signaling to develop.

Consider the idea of an "auction ring" as referred to in the Wolfstetter article [8]. The set of bidders have colluded and decided to have one of the players bid a certain price, while the rest of the players will either abstain or bid very low. In a first price or Dutch auction, the other players will have an incentive to slightly outbid the selected player to win the auction. Thus the agreement is *not* self-enforcing. However, in a second price or English auction, the selected player can bid just up to his valuation while the other players bid low, and the resulting price paid for the item (the second price) is also low. Here, there is no incentive for a player to break the agreement because to do so involves bidding above the selected player and paying a price close or equal to the player's valuation. So collusion may be sustainable in an English auction. Therefore from the auctioneer's perspective, if collusive behavior is suspected to be a problem, a Dutch style auction is preferred.

Another problem that often plagues auctions is their ability to attract enough buyers. If there are too few bidders in an auction, it runs the risk of being unprofitable and inefficient [4]. An auction may not attract many bidders due to high entry costs or large asymmetries between the bidders. Asymmetric auctions will be discussed in the following section in more detail, but here it is instructive to develop the idea along with what is known as the "winner's curse." Consider a common value auction, or an auction where the item up for auction has a value which, while unknown, is the same for all bidders. Each bidder has his own private information about the worth of the item. The winner's curse results because the bidder that wins the item is the bidder who most overestimates the value. Bidders that are *weak*, or have relatively less private information about the item's value, are most likely to overestimate the value and suffer the winner's curse. Technically, if the private signals to the bidders are distributed symmetrically around the true value of the item, although the average bid will be close to the value of the item, the winning bid will necessarily be greater than the value. The example developed in Wolfstetter [8] involves students bidding on a jar of coins. Even though the average bid was below the value of the coins in the jar, the average winning bid was above the value so this resulted in a net loss to the eventual buyer.

Finally, other downfalls for auctions include reputation and predatory bidding, lower reserve prices, and poor auction design. A bidder can try to develop a reputation for out bidding any competing buyer in hopes that this will deter future competition and result in a lower winning bid. Reserve prices, especially in a second price auction with a small number of bidders, may be set too low. Even if the highest bid is efficient and profitable for the seller, the lack of a strong competing second bidder or minimum selling price may lead to an unprofitable auction. Finally, an auction may just be poorly designed so buyers can exploit a loophole such as backing out of an auction after attaining the winning bid.

3 Auctions with Asymmetric Information

Since we have now covered the basics of auction theory, including the various ways that auctions fail even when all players have the same information, we now examine the special case of asymmetric information among the bidders. The situation occurs when some bidders have superior information about the item up for auction. In the article by Hendricks and Porter [3], they study the auctioning off of oil tracts out at sea to determine if firms that own neighboring tracts to those up for auction benefit from the informational advantage regarding the expected profitability.

Their point of departure is a comparison of participation rates in auctions of tracts with and without neighboring firms. They find that even though "drainage tracts," or those with a neighboring firm, yield higher average profitability, participation rates in these auctions is lower than in auctions for tracts that are geographically separated from all existing tracts. The intuition is that a non-neighboring firm, knowing that they would have to bid against a more informed firm, will refrain from entering an auction to avoid falling subject to a winner's curse. However, it is important to note that it is *not* an optimal strategy for the non-neighboring firms to refrain from bidding. If this was the case, the neighboring firm would simply have to submit a bid just above the minimum bid for those tracts that were profitable. Of course, the optimal reply for a non-neighboring firm would be to slightly outbid the neighboring firm and win the profitable tract. So in terms of a Nash equilibrium set of strategies, all firms, informed and uninformed, must submit a bid.

The model proceeds as follows. Assume there are n uninformed firms and one informed neighboring firm. Define X to be private signals available only to the informed firm on the true value of the tract, V. Let z be public signals on V which are available to all. Let H be the total amount of information available about the tract value such that:

$$H = E[V|X, z]. \tag{7}$$

Let the bidding strategy of the uninformed firm be a distribution function G_i. Define σ to be the bidding strategy of the informed firm. Both G_i and σ are functions of the information that each of the firms have regarding the value of the tract. Let h be the realized expected value to the informed firm. If the function G is a distribution function of the maximum bids, then the payoff to the informed firm is:

$$\underbrace{G(\sigma(h))}_{Prob\ of\ Win} \cdot \underbrace{(h - \sigma(h))}_{Expected\ Gain}. \tag{8}$$

Similarly, the uninformed firm only has public information, so if they bid an amount, b, their expected gain is:

$$\underbrace{E[H - b - c|b > \sigma(h); z]}_{Expected\ Gain} \cdot \overbrace{F(\sigma^{-1}(b)|z)}^{Prob\ Outbid\ Informed} \cdot \underbrace{\Pi_{j \neq i} G_j(b)}_{Prob\ outbid\ other\ uninformed}. \tag{9}$$

Table 1: Average Net Profits (standard errors in parenthesis)

	Neighboring firm wins	Non-neighboring firm wins And neighbor bids	Non-neighboring firm wins And neighbor does not bid
Average Net Profits	6.71 (2.69)	-2.69 (0.86)	0.78 (2.64)

Hendricks and Porter, p874.

Notice that the expected value of the tract for the uninformed bidder includes subtracting off a constant, c, which may reflect cost advantages that would be present for the neighboring firm. This expectation is multiplied by the probability of defeating not only the informed firm, but also all the other uninformed firms. As Laffont [5] explains, "The probability of being the highest bidder with a bid of b, when the competitors are known, is simply the product of the probabilities of defeating each of the known competitors." A Nash equilibrium set of strategies can then be constructed from these two payoff functions. The authors show that while the equilibrium strategy of the informed firm is uniquely determined, the non-neighboring firms must randomize their bids. This makes intuitive sense because if the uninformed firms bid according to any predictable set of strategies, the more informed neighbor would either slightly outbid them or not bid at all if the tract was expected to be unprofitable. The informed firm can choose to bid only on profitable tracts, thus yielding a positive return on average. This implies that uninformed firms will make positive profits on some tracts, but lose money on the tracts that the informed firm bids low because of private information.

Given the predictions of the model, one can now turn to the results of these auctions to see if the bidding strategies and resulting profits of the firms are consistent with the theoretical model. The main empirical evidence is summed up in table 1. Notice that the informed neighboring firms do seem to be exploiting their informational advantage and yielding positive profits. This results from their ability to significantly shade down their bids and increase their margins on profitable tracts. The uninformed firm makes negative returns when the informed firm does not bid, a sign that the private information has shown the tract to be unprofitable. When both types of firms make a bid, the uninformed firm makes positive, though insignificant, profits on average. Overall, the non-neighboring firm has expected profits equal to -0.42 ($SE = 1.76$), which is not significantly different from zero. Thus the uninformed bidder does not suffer from a winner's curse in this model because he bids conservatively. This is consistent with the predictions of the model because in an auction with asymmetric information, though it is not optimal for an uninformed player to drop out of the auction, the informational advantage does yield higher profits. However, similar to profits in a normal competitive environment, the informed firm's profits are not as high as they would be if the uninformed firms did not bid.

4 3rd Generation Telecommunication Licenses

An interesting application of auction theory involves the recent third generation mobile spectrum licenses in the UK. Prior to the auction, four firms operated using second generation technology and the British government needed a way to auction off the rights for a more advanced "third generation" or "3G" technology. Paul Klemperer and Ken Binmore [1] led a team to develop the *optimal* auction rules for allocating the licenses. In this case, an optimal auction is not only one that generates the maximum revenue for the seller, but it also must be efficient in the sense that the most worthy firm earns the license. Finally, it must promote a competitive environment because the item up for auction is not a tangible one, but rather a license to do business and the price passed on to the consumer is of primary concern.

The auctioning off of the radio spectrum had been used before, specifically in the 1994 allocation of the US 2G licenses. They have had mixed reviews from economists as some have been more successful than others. As Binmore and Klemperer point out, often poor design and implementation are the causes of an unsuccessful auction. Auctions are not *one-size-fits-all* by any means. Factors such as the number of incumbent and entrant firms, the value and number of licenses, and the style of the auction are very important.

With five licenses up for auction and four incumbent firms, the chosen auction design was an ascending first price auction. Similar to the Hendricks and Porter model of oil tracts, the incumbent firms had a large cost advantage over the potential entrant firms. Just as the neighboring oil drillers had an informational advantage about the profitability of the tract, the entrant firms in the 3G auction had a higher value of c as in equation 9. However, the result is similar. In both cases it becomes even more important to be able to attract bidders. With more licenses than incumbents, outside firms were more willing to enter the auction in hopes of winning, at the very least, one of the licenses. To make it even more attractive, the licenses were not of equal size and the largest was designated to the entrant firms alone, though entrants could still bid on the other four licenses. The major cost advantage for the incumbent firms was the infrastructure that currently existed from the second generation technology. To alleviate this problem, the auction rules guaranteed that any entrant firms that won a license would be able to roam on one of the incumbent's 2G networks.

4.1 Bidding Behavior

The auction design was rather unique in that it was a multi-unit, multi-round auction. All five licenses (A, B, C, D, E) were up for auction simultaneously, and the auction was not over until all five licenses were sold. In each round, players could bid on any one of the licenses as long as they did not hold one of the highest bids in the previous round. The A license, the largest of the five, was available for bidding only among the entrant firms. At each round, a bidder who currently did not have the highest bid on any of the licenses in the previous round could either put forward a bid on exactly one of the licenses that was at least a specified amount above the highest current bid, or he could withdraw from the auction. The auction ended when only five bidders remained, and they would each then have to pay their current bid.

Borgers and Dustman [2] studied the bidding behavior of the four incumbent and nine entrant bidders. They were trying to test the assumption that the bidders employed *private value - straightforward bidding.* Under this type of bidding behavior, firms have only private information about the value of the licenses, and these values are not affected by the way the auction proceeds. Straightforward bidding means that in each round in which a firm is active, it compares the minimum required bid it needs to make with its private valuation of each license. The firm then bids on the license that maximizes this surplus.

For example, the A and B licenses were approximately the same size though they were larger than the C, D, and E licenses, which were identical. Let the A and B licenses represent the "large" licenses and let C, D, and E represent the "small" licenses. Assume that a firm has approximately the same valuations for both large licenses (V_L) and the same, though smaller, valuation for each of the small licenses (V_S). Thus in each round, a firm would choose to bid on a large license if and only if:

$$V_L - M_L > V_S - M_S, \tag{10}$$

where M_L and M_S represent the minimum required bid for a large and small license respectively. Rearranging,

$$V_L - V_S > M_L - M_S. \tag{11}$$

Thus bidders will bid for a large license if and only if the difference in their valuations is greater than the difference in minimum required bids. This has clear parallels to a consumer who would be more likely to buy a higher quality good only if the price premium that must be paid is relatively small.

Borgers and Dustman found that within the large and small licenses, bidders behaved approximately according to the straightforward bidding hypothesis. However, the way that bidders choose between bidding for a large versus a small license is surprising. The strangest example is the bidding behavior of BT Cellnet (BT). Since BT was an incumbent firm, it could not bid on license A. Thus in a round by round graph of the difference, Price$\{B\}-$Minimum Price$\{C, D, E\}$, the authors plot the bids for large and small licenses by BT. If BT was bidding straightforwardly, then all their bids for a small license would be near the top of the graph when the difference in prices was large, and all their bids for license B would occur near the bottom of the graph when the difference was small (i.e. when the price premium for quality was low). This idea held until about round 100 when the theory breaks down, and BT started bidding against an incumbent firm, Vodafone, for the large B license even though they had bid for the smaller licenses when the difference was smaller. TIW, the entrant firm who eventually won the A license, also exhibited the same mysterious behavior, particularly in the later rounds of bidding.

So what can explain these violations of what seems to be a reasonable and rational bidding behavior hypothesis? One possibility is that the private value assumption is not accurate. Since this is an oral (non-sealed) auction where firms can observe the bidding behavior of other firms, it is possible that a firm will revise its valuations of the licenses once it sees how the others are bidding. For example, aggressive bidding by one firm might signal another firm that its valuation is too low.

Financial constraints are a likely reason for withdrawal from an auction. Given two firms of similar financial capacity, the withdrawal of one firm from the auction might signal the other to withdraw as well. In the 3G auction, there is evidence of this in the short period of six rounds (94-100) where five firms withdrew from the auction. This could be the result of firms all reaching the limits of their finances at the same time, but more likely, firms began to revise their valuations as others left the auction.

Finally, there may be a reason why firms do not bid straightforwardly. As mentioned earlier, this auction is not for a tangible item, but rather, these firms are bidding for the right to compete with one another after the auction. This could imply two types of behavior. First, incumbent firms may prefer that entrant firms win the other licenses under the premise that they will be a lesser competitor after the auction. Some form of collusive behavior would be necessary for this to occur. The other result involves the strategy of the entrant firm. Knowing that an incumbent, whose entire 2G customer base is possibly at stake, is more likely to outbid any competing firm, an entrant firm might bid up the price of one license and then switch to another cheaper license later just to force the incumbent to pay the higher price. This is possibly what BT was doing in the late rounds by bidding against Vodafone on license B even when the price difference between the large and small licenses was so great.

Morgan, Steiglitz, and Reis [7] analyze what they call *relative profit auctions*, or auctions where players not only care about their own payoffs but also about their payoffs relative to the other players. In an auction for a single item, the authors show that it is sometimes optimal to bid above one's valuation because the possible loss associated with the risky bid is more than offset by the lower resulting payoffs (i.e. higher resulting prices) to the competition. This can be directly applied to the 3G multi-unit setting, although here firms bid up the price of one license only to switch to another later in the auction. Given the huge costs of setting up and running a 3G network, an entrant firm might be able to narrow the financial gap between him and the incumbent by forcing the incumbent to overpay for the license.

4.2 Anglo-Dutch Style Auction

The Anglo-Dutch style was an interesting auction design introduced as the 3G auction was being developed. Originally, the UK auction was supposed to involve only four licenses, which would create problems in a strictly ascending price auction with four incumbents. Collusive behavior becomes more common, and there is virtually no incentive for an entrant firm to participate due to the large cost advantages among the incumbents (though participation is still an optimal reply). The solution was an auction that started with a classic ascending price round until there were only two bidders remaining. Then the two bidders would place final sealed bids at a price greater than the highest price in the ascending round. The idea is that the sealed bid round attracts entry from outside firms into the auction.

A strictly ascending price auction is usually won by the bidder with the highest valuation. If there is very little competition, the winning bid may not be as high as in a sealed bid auction. The sealed bid round attracts entrants because there is now the possibility that an entrant may win the auction even though the incumbent would have been willing to bid more if he had the opportunity. The advantage of having the ascending price rounds is that it allows bidders to gain information about each other and results in a more efficient outcome. In the UK auction, an additional license was added, and therefore a first price ascending style auction was appropriate. However, it is fairly easy to see that there are cases where an Anglo-Dutch style would be optimal.

4.3 The Results and Critiques

In the end, after 150 rounds of bidding, the UK 3G auction raised 22.5 billion pounds, which was five to ten times the initial estimates. Licenses B,C,D, and E each went to incumbent firms while the A license was, of course, awarded to an entrant. Note the price paid for the most valuable A license was not the most expensive license. This results from the lack of competition for this license from the incumbent firms. Vodafone, bidding against BT in the late rounds for license B, ended up winning the license, but paid 2 billion more for it than was paid for the smaller licenses.

The UK style auction was imitated in other countries, though with much less success. Klemperer and Binmore's "horses for courses" argument could not be more clear when looking at the auction in the Netherlands, for example. They exactly followed the UK auction by running an ascending first price auction; though there were an equal number of incumbent firms and licenses. Due to the lack of incentive for entrant firms to participate and possibly some collusion among the incumbents, the auction generated a fraction of what was predicted. Klemperer [4] recommended that the Anglo-Dutch style may have been more appropriate. Similar results occurred in Italy due to collusive behavior among the bidders.

The 3G auctions provide a clear example of how issues of industrial organization are very important when determining the correct auction design. When social efficiency is one of the objectives in an auction, it is not enough just to let the market decide. The *auction market* is very different from the end market, which in this case is mobile phone service. Careful planning and thought is required to run an auction that is revenue maximizing, efficient, and generates a competitive environment among the winning firms.

5 Conclusion

This paper has examined the basic theory and implementation of auctions and looked at the case of asymmetric information among buyers. Specific reference was made to the recent auctioning off of the radio spectrum for third generation mobile technology. It has been shown that an auction is a bidding mechanism that allows sellers to gain reasonable estimates of the willingness to pay of potential buyers. This creates a revenue maximizing and efficient outcome that is now used to facilitate the sale of everything from art and wine to treasury bills and oil drilling rights.

The case of telecom license auctions, which have now occurred in many countries of the world, has made clear the idea that auction design is crucial in determining the level of success. Auctions are by no means *one-size-fits-all*. The particular characteristics of each auction and who the potential bidders are must be examined both on a theoretical and experimental level to achieve the best chance for a successful auction. However, even then, informational asymmetries like those in the Hendricks and Porter article and cost asymmetries inherent in telecom auctions may make finding the *optimal* auction design very difficult. The gains from doing so, 22.5 billion pounds in the UK alone, make auctions a profitable area of economic research that will surely only grow as individuals, firms, and governments seek to achieve the optimal allocation of their goods and services.

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