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43 A Market-based Approach to Establishing Licensing Rules: Licensed Versus Unlicensed Use of Spectrum

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Abstract

The FCC uses an administrative process for identifying the most desirable set of licensing rules for spectrum. Spectrum designated to unlicensed use is made freely available for uses which comply with appropriate technical standards. Spectrum allocated to licensed use is generally awarded to private parties through an auction mechanism. The allocation between licensed and unlicensed use, however, is based on the FCC's judgment, which in turn relies on information provided by interested parties who seek to use the spectrum. One method of reducing the incentive that parties have to exaggerate the value they place on a given regime involves creating a market for such rules. We examine the feasibility of using a "clock auction" to determine, based on the bids submitted by market participants for the corresponding licensing rules, the efficient allocation of a given amount of spectrum between licensed and unlicensed spectrum use. Analysis indicates that market forces, in the form of a clock auction, can be used to determine the efficient assignment of license rules to spectrum.

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1 Introduction

Like many other telecommunications regulatory bodies, the Federal Communications Commission (FCC) uses an administrative process for identifying the most desirable set of licensing rules for a given band of spectrum. An important recent example involved the use of that process in establishing licensing rules for 22 MHz in the 700 MHz band.[3] Here, the FCC faced the highly contentious issue of whether to impose an "open" versus a "closed" platform requirement on the license owner of such a block. Under an "open" platform requirement, the license owner would be prohibited from restricting the set of wireless devices that a customer can employ on the licensee's network and the applications the customer can access via that network.[4] In contrast, under a "closed" platform regime, the license owner would not be so prohibited. Traditional service providers (e.g., Verizon, AT&T) argued strongly that the platform should be closed, while several interested parties (e.g., Google, Skype, Frontline Wireless) maintained that the platform should be open.[5]

Some regulatory bodies have expressed substantial dissatisfaction with the use of an administrative process to make such decisions.[6] The dissatisfaction stems, in part, from the manner in which the process obtains information on the value users place on alternative spectrum license rules. In contrast to a market mechanism, where users pay a price for having their needs met, an administrative process relies simply on the reported needs of interested parties. Because of the cost of misrepresenting one's needs is small relative to the potential private value of spectrum acquired, each user has an incentive to exaggerate the value he/she places on a given set of licensing rules, as well as how much spectrum to which those rules should apply.

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[3] See Federal Communications Commission, *Second Report and Order*, WT Docket No. 07-132, July 31, 207. Another example involves the identification of the most efficient set of license rules for Advanced Wireless Services in the 2155-2175 MHz Band. See Federal Communications Commission, *Notice of Proposed Rulemaking*, WT Docket No. 07-195, September 19, 2007.

[4] Currently, carriers typically restrict the models of cell phones that can be employed on their networks as well as the software that can be downloaded onto the cell phones that can be employed on their networks.

[5] On September 13, 2007, Verizon filed a suit before the U.S. District Court of Appeals for the District of Columbia arguing that the FCC's open access requirements were unlawful. On October 23, 2007, Verizon decided to drop its lawsuit after losing its appeal for a speedy resolution on October 3, 2007. On that same day, the Cellular Telephone Industry Association (CTIA) stepped in to challenge the same regulation in a lawsuit before the Court. See "CTIA Takes UP 700 MHz Challenge," *RCR Wireless News,* October 26, 2007.

[6] The European Commission has recently stated that an administrative process for determining licensing rules is neither transparent nor objective. See *Study of Legal, Economic & Technical Aspects of "Collective Use of Spectrum" in the European Community – Final Report,* by Mott MacDonald Ltd., Aegis Systems Led., IDATE, Indepen Ltd, and Wik Consult (November 2006), pg 13. Recently, Professor Martin Cave called the administrative approach to determining license rules "arbitrary and unsatisfactory." See "New spectrum-using technologies and the future of spectrum management: a European policy perspective," by Martin Cave, in *Communications: The Next Decade,* edited by Ed Richards, Robin Foster and Tom Kiedrowski, Ofcom (November 2006), pg. 224.

Therefore, identifying the most desirable set of licensing rules involves both measuring an interested party's "need," and determining the magnitude by which interested parties have exaggerated their license rule needs. The FCC's license rule assignment problem is similar to other assignment problems where an administrative process is used to identify the best use of a given resource. For example, city planners are often confronted with the problem of determining whether a given parcel of land should be designated to public or private use.

The FCC's license rule assignment problem is an example of a broader class of "incentive problems" that have been considered in the economics literature. In this instance, a potential solution involves creating a mechanism that induces interested parties to reveal their private information regarding the value they place on spectrum and the licensing rules that apply to that spectrum. One approach, which is explored in this paper, involves the creation of a market for licensing rules in which participants bid to have their licensing rule needs met. By reducing the incentive that interested parties have to misrepresent their economic interests, this approach may substantially improve the efficiency of the licensing process and, thus, the economic benefit society receives from one of its most valuable resources.

Licensing rules come in a wide variety of flavors. We examine, using experimental methods, the issue of whether a particular market form can determine an efficient designation of a given amount of spectrum between licensed and unlicensed use. Specifically, we experimentally examine the ability and willingness of market participants to compete, via a clock auction, to have a number of homogeneous units of spectrum designated to licensed versus unlicensed use. The clock auction is an ascending price auction wherein bidders reveal to an administrator the number of blocks of spectrum they wish to "acquire" at different clock prices established by an administrator. The auction concludes when the demand for spectrum is consistent with the available supply at that clock price. Because each bid is associated with a given license regime, the identification of the efficient assignment of spectrum simultaneously determines the efficient set of licensing rules for the blocks of spectrum up for auction, given the bids submitted in the auction. Once the efficient allocation of spectrum is identified, a simple rule determines the price(s) paid by winning bidders.

2 Modeling Licensing Rules – Licensed and Unlicensed Operations

As part of its spectrum management responsibilities the FCC determines the set of rights that are assigned to a given block of spectrum used by commercial and non-commercial entities.

At one end of the spectrum rights regime are unlicensed operations. Under unlicensed operations, spectrum is treated as an open access resource that is available to all without charge.[7] Each user is free to demand as much spectrum as he/she wishes employing the appropriate FCC-certified equipment, which operates at the authorized power levels. However, the service quality, in terms of transmission speed, jitter and packet loss, experienced by a given user depends on the total spectrum demand of all users. In particular, if the sum of the demands that users place on the available spectrum is less than some percentage of the available supply, the quality of service is satisfactory for all users. On the other hand, if total demand for spectrum exceeds the available supply, spectrum is assigned to the competing users in a manner that reduces the quality of service for all.[8] The most successful example of unlicensed operations is Wi-Fi service, a service that operates in the 900 MHz, 2.4 GHz, and 5.8 GHz bands and which is employed by millions of users each day to access the Internet.[9]

At the other end of the spectrum licensing regime are licensed operations. Under licensed operations the license owner is granted the right to determine the service to be offered, the technology to be employed to provide that service, and the right to exclude non-payers from accessing his/her service. In addition, the license owner is assigned a right that protects his/her service from harmful interference from other service providers, as well as the right to sell his/her license to another party. A prominent example of licensed operations is the highly successful Personal Communications Service which operates in the 1.9 GHz band.

In modeling the licensing rule problem, we assume that, as a result of its engineering and policy analysis, the FCC has established a set of technical performance parameters, including maximum power and out-of-band emission limits, for a set of four bands of spectrum located in a

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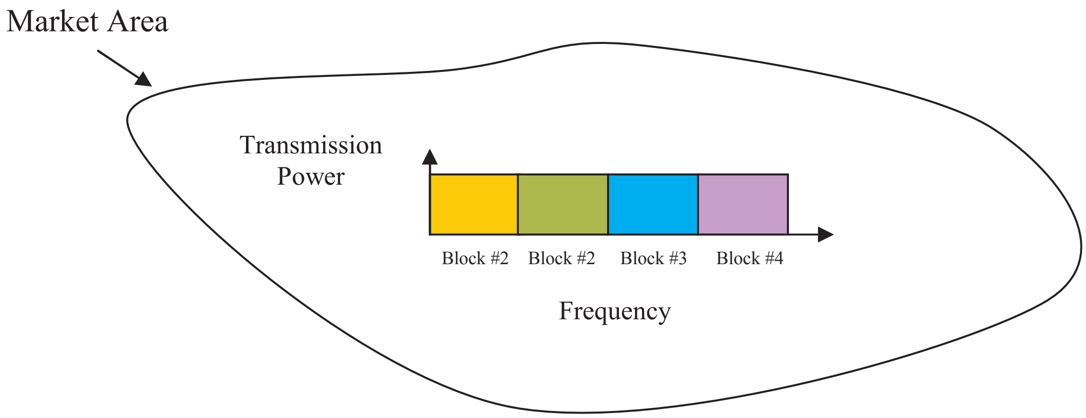
[7] While spectrum is available to makers of FCC authorized devices without charge, whether spectrum is fee to users depends upon the service and the business enterprise. For example, Panera Bread offers free Wi-Fi service to its customers, while Starbucks does not.

[8] Because of differences among spectrum users on the effect spectrum congestion has on the value they place on spectrum, the economic relationship between quality of service, spectrum congestion, and valuation is more complicated in actuality than specified here. For a discussion of this economic relationship, see Bykowsky, M., Olson, M., and Sharkey W. (2008) "Modeling the Efficiency of Spectrum Designated to Licensed Service and Unlicensed Operations," *OSP Working Paper #42*. Some writers use the word "interference" to describe the problem of spectrum congestion. See Stuart Benjamin (2003), "Spectrum Abundance and the Choice Between Private and Public Control," *New York Law Review*, vol. 78, Number 6, pgs 2007-2102.

[9] More precisely, the FCC has authorized devices to operate on an unlicensed basis in these bands**.** Moreover, technological improvements continue to enhance the transmission capabilities of spectrum designated to unlicensed operations. Such improvement may in the future prove effective in enhancing competition in the broadband access marketplace.

single geographic area (see Figure 1).[10] We further assume that, as part of its traditional spectrum management responsibilities, the FCC is confronted with the problem of identifying whether each block should be designated to either licensed or unlicensed operations, and, for licensed operation it must further identify the user(s) that most highly value the block(s). The current analysis assumes that equal power is designated for all block of licensed or unlicensed spectrum.

Figure 1: Hypothetical Band Plan



3 Modeling Auction Participant Type

In an auction to allocate spectrum between licensed and unlicensed use, participating firms fall into two distinct categories as a result of differences in their business models. The business model of "L-Type" firms (e.g., Verizon, AT&T, T-Mobile) involves constructing the necessary telecommunications infrastructure and earning a return on that investment based on revenue obtained from subscribers. Consequently, all L-Type firms strongly prefer to acquire spectrum

[10] Spectrum congestion is a problem for all service providers, regardless of whether they utilize spectrum designated to licensed use or spectrum designated to unlicensed operations. However, due to the free entry conditions of unlicensed operations, congestion is considered a greater problem under unlicensed operations than licensed use. To reduce the likelihood of congestion, the FCC typically authorizes a lower power limit for unlicensed operations than licensed use. Nevertheless, we assume in this analysis that there is no difference in authorized power levels between the two service types. The assumption is appropriate if certain enforceable congestion protocols are established within the unlicensed spectrum bands. For a discussion of several possible protocols, see Bykowsky, M., Carter, K, Olson, M., and Sharkey W. (2008) "Enhancing Spectrum's Value Through Market-informed Congestion Etiquettes," *OSP Working Paper #41*. For a discussion of the incentive equipment manufacturers have to design unlicensed devices that are "greedy," thereby increasing the likelihood of spectrum congestion, see Peha, Jon, " Spectrum Sharing Without Licenses: Opportunities and Dangers," in *Interconnection and the Internet: Selected Papers From the 1996 Telecommunications Research Conference*, G. Rosston and D. Waterman (Eds). Mahwah, N.J.: Lawrence Erlbaum Associates, 1997, pgs. 49-75.

with licensing rules that enable them to exclude non-payers and to receive protection from harmful interference from other service providers.

Another type of bidder – a "U-Type" firm – has a preference for licensing rules that promote free, open access to spectrum. A variety of firms fall within the U-Type category. Rather than derive revenue from subscribers, one class of U-Type firms earns revenue from advertisers and/or retail customers that sell good/services to customers via the Internet. The most prominent examples are firms (Ask.com, Google, Microsoft, Yahoo) that obtain revenue from selling to advertisers access to viewers/listeners that are attracted to Internet-based content and services. Another class of U-Type firm (Cisco, Fujitsu, Juniper Networks, Motorola) obtains revenue from selling hardware (e.g., wireless routers) to firms that provide Wi-Fi service (Marriott Hotels, Panera Bread, Starbucks) or obtains revenue directly from consumers that purchase products (e.g., cellular handsets or automatic garage door openers) that utilize spectrum designated to unlicensed operations.

The greater the number of viewers or users to which a U-Type firm can obtain access, all things being equal, the greater the value it places on licensing rules that provide for non-exclusive, open access use. It also follows that the greater the demand for a product that is necessary to either provide Wi-Fi service or to enable consumers to utilize spectrum designated to unlicensed operations, the greater the value the U-Type firm places on licensing rules that provide for non-exclusive, open access use. Because market participants vary in the demand for their products, as well as in their profit margins, U-Type firms will vary in the value they place on having spectrum allocated to unlicensed operations, but they nevertheless have a common interest in obtaining spectrum authorized for unlicensed use.

4 Modeling Bidder Preferences and Valuations

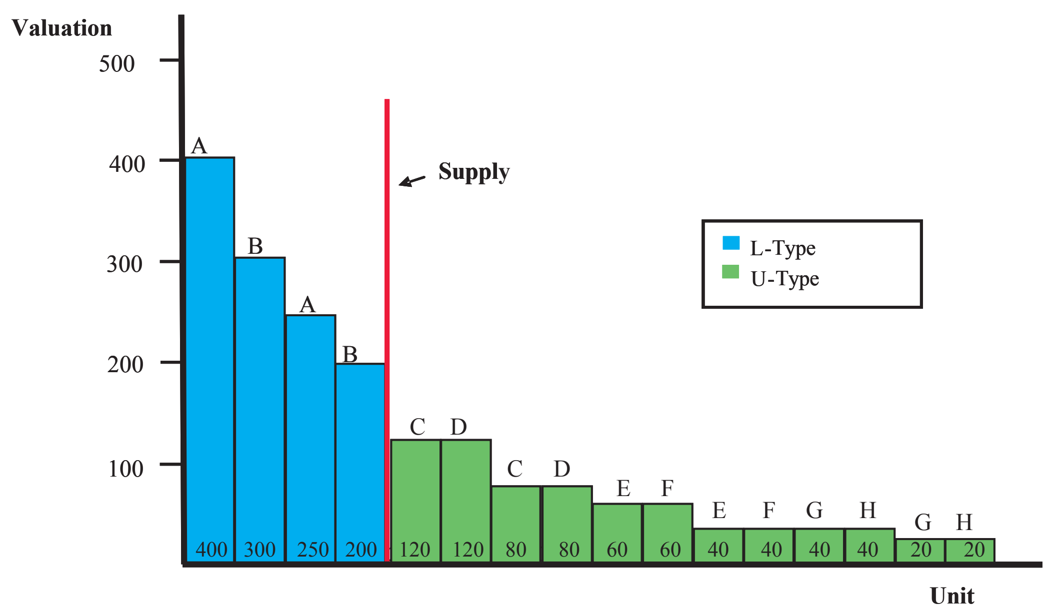
Under the current FCC administrative process to determine the amount of spectrum assigned to market participants, it is possible that the spectrum assigned to any given user is less than what that user desires. This mis-estimation makes it likely that market participants will desire multiple blocks of spectrum. However, legitimate concerns about system congestion also create a demand for multiple blocks for any given user.[11] Because of diminishing marginal revenue product considerations, the value each firm places on the first block of spectrum may exceed the

[11] See Bykowksy, et al. (2008), *op cit.*

value a firm places on additional blocks of spectrum.[12] In addition, given the stronger ownership and use rights associated with spectrum designated to licensed versus unlicensed operations, our model assumes that L-Type firms uniformly place a higher value on a block of spectrum than U-Type firms.[13]

In this analysis, the actual values assigned to market participants are driven less by actual market valuation considerations derived from empirical data than by a desire to stress test our market approach to achieving the efficient allocation of spectrum. In particular, we wish to establish a valuation environment that tests whether the proposed mechanism efficiently designates spectrum to unlicensed operations when it should clearly do so. Moreover, we wish to establish a valuation environment that tests whether the mechanism finds the efficient set of license rules when to do so is highly problematic. To that end, we have established two valuation environments. Under one set of valuations (Session 1), there are two L-Type bidders (A and B), and six U-Type bidders (C through H). Figure 2 shows the distribution of valuations across these bidders in this environment.

Figure 2: Session 1 Valuations

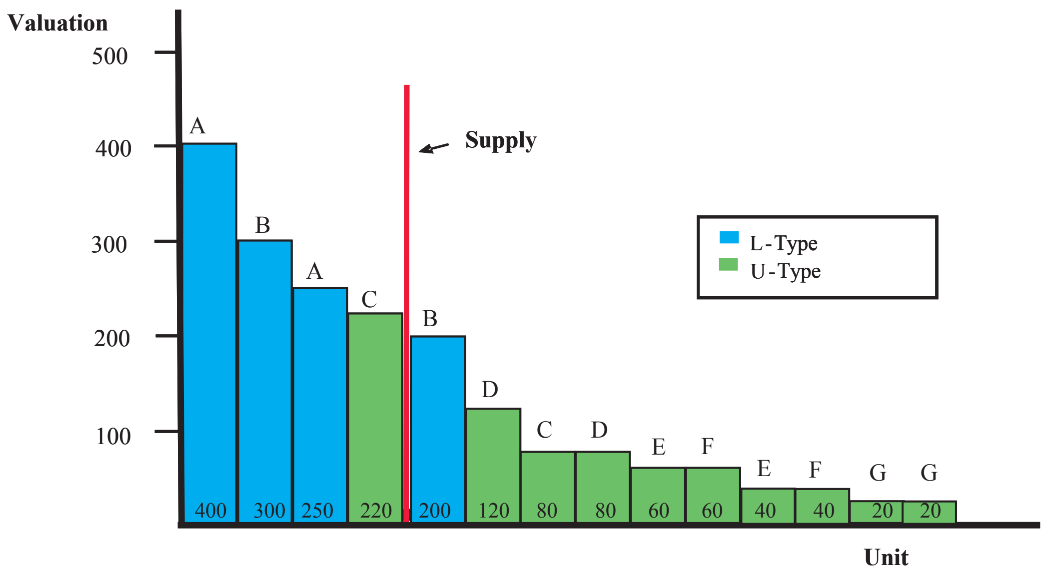


[12] A market participant's demand for spectrum is derived from the demand consumers express for the participant's wireless service. In a competitive market, consistent with a firm's attempt to maximize its profits, a firm will acquire spectrum to the point where its marginal revenue product of spectrum is equal to its cost.

[13] The fact that a U-Type firm has never participated in a spectrum auction, let alone place a winning bid in an auction, provides weak proof that up to now U-Type firms place a lower value on a given block of spectrum than L-Type firms.

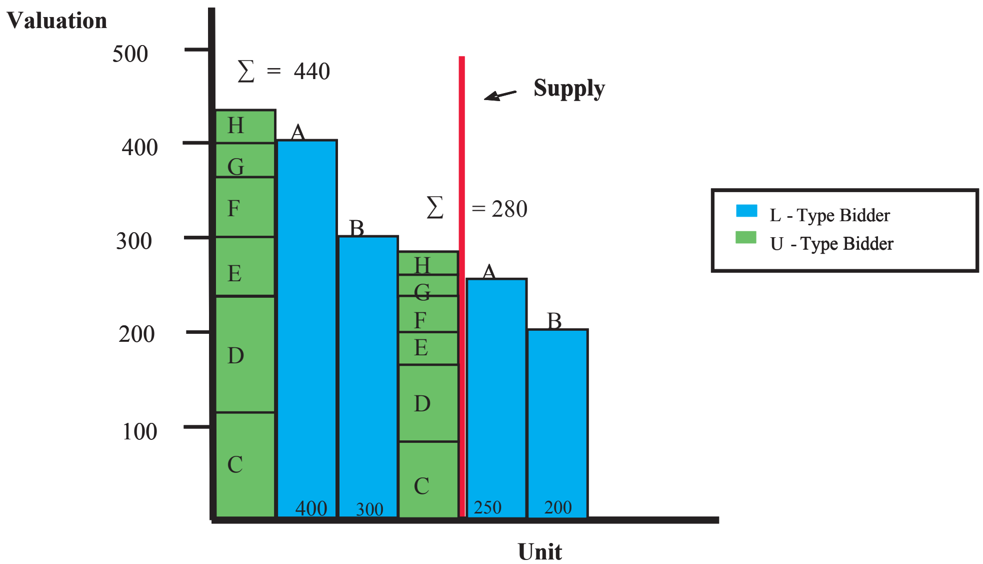
Under another set of valuations (Session 2), there are two L-Type bidders, and five U-Type bidders. Figure 3 shows the distribution of valuations across these bidders in this environment.

Figure 3: Session 2 Valuations



Because each bid is associated with a given license regime, the identification of the efficient assignment of spectrum simultaneously determines the efficient set of licensing rules for the blocks of spectrum up for auction and the set of winning bidders, given the bids submitted in the auction. Identifying the economically efficient set of licensing rules involves measuring the value society would receive from each set of license rules. The value society obtains from having one or more blocks of spectrum allocated to licensed operations is equal to the value L-Type firms place on licensed operations. In contrast, the value that society obtains from having one or more blocks of spectrum designated to unlicensed operations, given their unfettered open access nature, is equal to the summation of the valuations that U-Type subjects place on having such a designation. Figure 4 shows the efficient assignment of spectrum, including the efficient set of licensing rules, involving Session 1's valuation set. As shown, efficiency considerations dictate that one block of spectrum be assigned to subjects A and B (for licensed operations) and two blocks of spectrum to subjects C – H (for unlicensed operations).

Figure 4: Session 1 Efficient Assignment



The objective of our analysis is to examine – in proof of concept terms – whether a market can be used to allocate spectrum between licensed and unlicensed operations.[14] At the minimum, the chosen market mechanism should designate spectrum to unlicensed operations where it is obvious, from an efficiency perspective, that it should do so. Here, we define the level of "obviousness" by the size of the discrepancy between the value U-Type bidders place on having spectrum designated to unlicensed operations and the value society would receive from having the extra-marginal unit included in the allocation. For example, as shown in Figure 4, the sum of the values U-Type subjects place on having spectrum designated to unlicensed operations (i.e., 440) is substantially greater than the value Subject A places on a second block of spectrum (i.e., 250). Therefore, in this environment a successful mechanism is one that nearly always designates at least one block of spectrum to unlicensed operations.

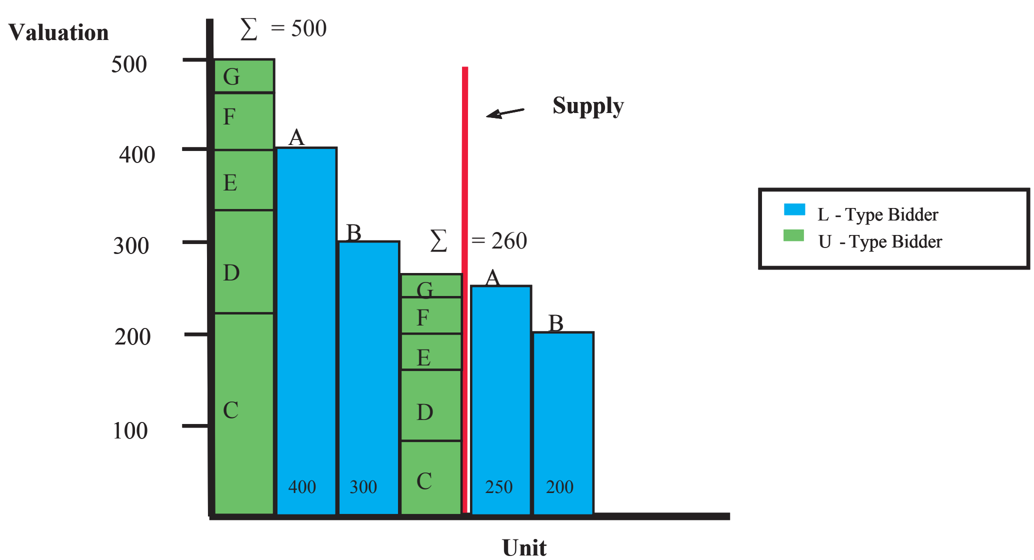
Ideally, the chosen market mechanism should also designate spectrum to unlicensed operations in instances where just a small amount of under-revelation by U-Type participants would cause the market to designate spectrum to licensed operations when efficiency considerations dictate it should be designated to unlicensed operations. One measure of the degree of difficulty U-Type firms will have in overcoming the under-revelation problem is represented by the amount of value they collectively must give up in order to obtain a given

[14] A Proof of Concept is a realization of a given process or technique that is designed to demonstrate the feasibility and workability of a set of core ideas.

amount of value. How much value U-Type firms need to give up depends on the mechanism's pricing rule. As will be discussed later, under the proposed mechanism all blocks of spectrum are sold at a uniform price which is equal to the highest rejected bid. For example, as shown for Session 1 in Figure 4, in order for U-Type firms to collectively obtain 30 units of value from having a second block of spectrum allocated to unlicensed use (i.e., 280 -250), they must give up 250 units of value (88% of the combined total value).

Figure 5 shows the efficient assignment of spectrum, including the efficient set of licensing rules for Session 2's valuation set. As before, efficiency considerations again dictate that one block of spectrum should be assigned to bidders A and B under licensed operations, and two blocks of spectrum to bidders C – H under unlicensed operations. As measured by the difference in value between the fifth highest valuation (i.e., 250) and the value U-Type bidders collectively place on having a first block of spectrum allocated to unlicensed operations (i.e., 500), a successful mechanism is one that consistently designates at least one block of spectrum to unlicensed operations. While the Session 2 two valuation environment poses less of an allocation challenge for the market mechanism regarding the first block of spectrum, it is substantially more difficult than Session 1 regarding the second block of spectrum. As shown in Figure 5, in order for U-Type bidders to obtain 10 units of value (i.e., 260 – 250) from having a second block of spectrum allocated to unlicensed use, collectively they must give up 250 units of value (96% of the combined total value).

Figure 5: Session 2 Efficient Assignment



5 Market Mechanism – A Clock Auction

Experiments conducted for other spectrum auctions have revealed that bidders may engage in "jump bidding" in an ascending English auction in an effort to forestall or signal competition and, as a result, may lead to an inefficient assignment of items.[15] More recently, analysis indicates that the threat of financial exposure increases the likelihood of this behavior during a simultaneous multiple round auction involving multiple heterogeneous items.[16] Moreover, jump bidding appears to be a significant feature of FCC spectrum auctions.[17] One solution to this problem is a "clock auction." A clock auction is an iterative auction procedure where bidders express there willingness to pay for one or more units of an item based on prices established by the auctioneer and where a set of rules determines the efficient allocation and a set of market clearing prices.

In this study we propose a new auction mechanism that is based on, but not identical to, previous clock auctions.[18] The proposed auction begins with the Auctioneer (e.g., the FCC) announcing a single opening price – the clock price – for each spectrum block up for auction.[19] Subjects respond by identifying the number of blocks they wish to acquire at that clock price. All responses, including the identities and license regime preferences of bidders, are kept private. A simple set of rules enables the auctioneer to assess the value bidders place on having one or more blocks of spectrum designated to licensed versus unlicensed operations.

1. If a bidder requests zero blocks at the initial clock price, then the value the bidder places on the first and second blocks of spectrum is equal to zero.
2. If a bidder requests one block of spectrum at the initial clock price, then the value the bidder places on a second block of spectrum is equal to zero.

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[15] Jump bidding occurs in an ascending bid auction when one or more bidders place bids in excess of the minimum bid increment established by the auctioneer. See McCabe, K., Rassenti, S. and Smith, V. (1988) "Testing Vickrey's and other Simultaneous Multiple Unit Versions of the English Auction," revised by Isaac, R.M., ed. (1991) *Research in Experimental Economics* (JAI, Greenwich, CT), vol. 4. See also Avery, C., (1998) "Strategic Jump Bidding in English Auctions," *Review of Economic Studies*, Vol. 65 (2), pgs 185-210.

[16] Porter, D, Rassenti, S, Roopnarine, A, and Smith, V., (2003) "Combinatorial Auction Design," *Proceedings of the National Academy of Sciences*, vol. 100.

[17] Cramton, Peter, (1997), "The FCC Spectrum Auctions: An Early Assessment," *Journal of Economics and Management Strategy* Vol. 6(3), pgs. 497-527.

[18] The primary focus of our research, however, is directed to the feasibility of using a market mechanism to designate spectrum to either licensed or unlicensed use. We leave it to further analysis to determine the most appropriate auction design for this purpose.

[19] The number of clock prices is equal to the number of heterogeneous items. For simplicity, we have assumed that blocks up for auction were homogeneous.

3. To preserve the increasing price nature of the auction, bidders are prevented from increasing the number of spectrum blocks they desire as the clock price increases.
4. If a bidder reduces his/her spectrum block demand from two to one as the clock price increases from one level to the next, the lower clock price represents the value the bidder places on a second block of spectrum.
5. If a bidder reduces his/her spectrum block demand from one to zero blocks as the clock price increases from one level to the next, the lower clock price represents the value the bidder places for a single block of spectrum.
6. For subsequent rounds, if a bidder reduces his/her spectrum block demand from two to zero blocks in response to the latest clock price increase, the lower clock price represents the value the bidder places for both the first and second blocks of spectrum.

If the number of blocks desired by one or more bidders exceeds zero at a given clock price, the "clock ticks up" – meaning that the price for a block of spectrum goes up by a pre-determined amount.[20] Subjects are then given the opportunity to reveal to the auctioneer (and not to the market) the number of blocks they desire at that clock price. The auction closes when there is zero demand for a spectrum block at the going clock price.

5.1 Allocation Rule – Aggregate Bid Rule

When the auction concludes, the allocation of spectrum and the prices paid by winning bidders can be easily determined. The efficient allocation of spectrum across license regime type and users requires comparing, based on the represented willingness to pay of bidders for spectrum designated to different use types, the value society will obtain from designating spectrum to licensed versus unlicensed use. In contrast to licensed use where license owners have exclusive use rights to the allocated spectrum, unlicensed users have unfettered access to spectrum designated to unlicensed operations. The open access provision of unlicensed operations requires that we apply the same "non-exclusive" treatment to the bids submitted by bidders that wish to see spectrum designated to unlicensed operations. Such treatment requires that we aggregate the bids U-Type bidders place in the auction. In our model, where bidders

[20] In most clock auctions, the clock price only ticks up if the demand for the auctioned item exceeds its supply. See Porter, et. al. (2003) *op cit*.

desire to have multiple blocks of spectrum designated to a given license regime and where they have different willingness to pay across these blocks, such aggregation must be performed with care. For example, because U-Type bidders may express a higher valuation for a single block of spectrum than for a second block of spectrum, such bidders are submitting to the auction two distinct bids – one type applies to a single block of spectrum, while another type applies to a second block of spectrum.[21] Forming the correct aggregate bids requires keeping this distinction in mind. To this end, a simple algorithm adds together the highest bids from each U-Type bidder to form one aggregate bid – (U1). In addition, a simple algorithm adds together the lowest bids from each U-Type bidder to form a second aggregate bid (U2).

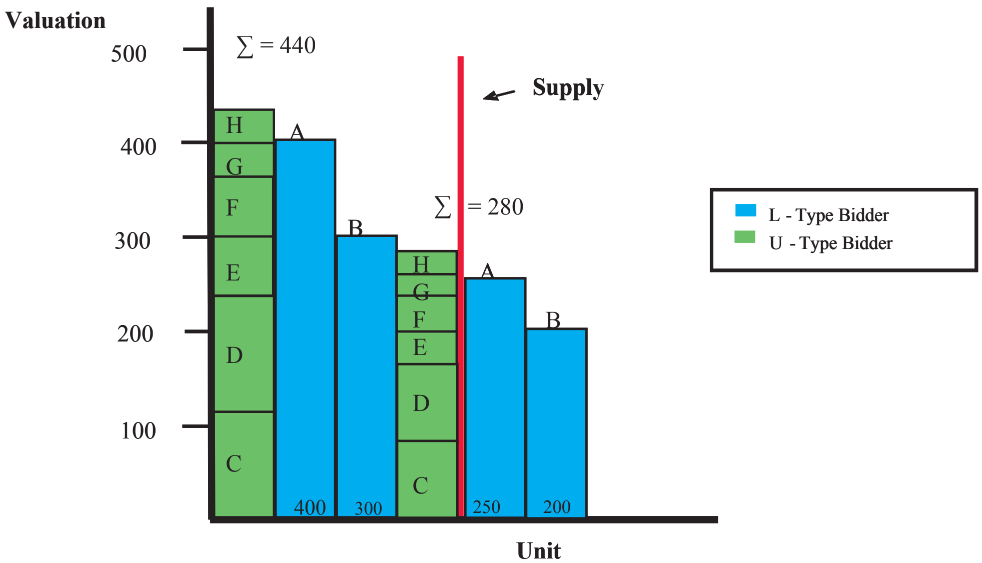
Once the two aggregate bids are constructed, identifying the efficient allocation of spectrum to license rule regime and, in the case of licensed operations, to the most efficient user(s) is straightforward. Under the allocation rule, bids U1 and U2 are ranked, along with the bids submitted by L-Type bidders, from highest to the lowest. Given that there are four blocks of spectrum up for auction, the four highest bids are each assigned a single block of spectrum. Because each bid is associated with a given license regime, this assignment also determines whether a block is allocated to either licensed or unlicensed operations. For example, if the U1 and U2 bids are among the four highest bids, two blocks are designated to unlicensed operations. If the four highest bids include two bids from L-Type bidders, then two spectrum blocks are allocated to licensed operations and to the bidders whose bids were among the four highest bids.

A simple example can be used to illustrate the allocation and aggregate bid formation rule. Consistent with the information shown in Figure 4 (which is reproduced as Figure 6 below), suppose the auction has closed and that bidders have truthfully revealed the value they placed on having two blocks of spectrum allocated to either licensed and unlicensed operations.[22] Under these assumptions, the clock auction would generate an outcome in which two blocks of spectrum are assigned to bidders A and B on a licensed basis, and two blocks of spectrum are designated to unlicensed operations.

[21] Licensed bidders also submit distinct bids for the first and second units of desired spectrum.

[22] Truthful bidding is assumed here only to illustrate the allocation and pricing rules in the auction mechanism. Later, it will be demonstrated that unlicensed bidders rarely have an incentive to bid completely truthfully.

Figure 6: Session 1 Efficient Assignment

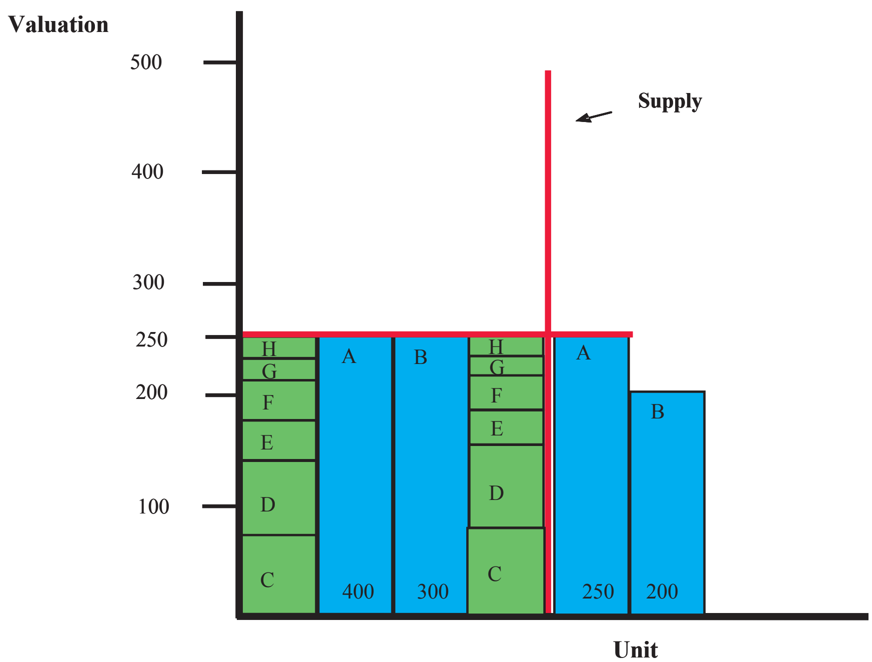


5.2 Pricing Rule

The "public good" aspect of the demand by unlicensed bidders also gives rise to a "threshold" problem, in which U-type bidders must coordinate their bidding strategies in order to reach a favorable outcome. The presence of a threshold problem highlights the importance of establishing a pricing rule that encourages subjects to reveal the value they place on having spectrum allocated to one use type or the other. To that end, because of its favorable incentive properties, all trades in the experimental study occur at a uniform price, where this price is equal to the highest rejected bid. In the above example, because there are four blocks of spectrum up for auction, the highest rejected bid is equal to the fifth highest bid, including U1 and U2. While L-Type bidders pay the highest rejected bid, U-Type subjects that bid in the auction pay a price that is "based on" the highest rejected bid. In particular, U-Type subjects that bid in the auction are assigned a cost that is proportional to the share their bids represented in the aggregate bid.

A simple example can be used to illustrate the above pricing rules. Continuing with the example shown in Figure 6, suppose the auction has closed and that bidders have truthfully revealed the value they placed on having spectrum allocated to licensed and unlicensed operations. As shown in Figure 7, under these conditions Bidders A and B would receive one block of spectrum each, while two blocks of spectrum would be designated to unlicensed operations. Under the auction's pricing rules, all four blocks are sold for a uniform price of 250, which represents the highest rejected bid. In addition, winning U-Type bidders are assigned a cost that is proportional to the share their bids represented in the aggregate bid. For example, consider Bidder C, a U-Type bidder, and its contribution of 120 to the aggregate bid for allocating a single block of spectrum to unlicensed operations. Because Bidder C's bid of 120 represents 27% of the value of the accepted aggregate bid of 440, under the adopted pricing rules Bidder C is required to pay 27% of the final transaction price (i.e., 250), or 68.2. Similarly, because Bidder C's bid of 80 to have a second block of spectrum designated to unlicensed operations represents 29% of the value of the accepted aggregate bid of 280, Bidder C is required to pay 29% of the final transaction price, or 71.4.

Figure 7: Session 1 Pricing Rule



To assist readers in visualizing the proposed clock auction, the authors have created a flash clip that demonstrates the major features of the described auction. The flash clip can be accessed at http://www.fcc.gov/osp/projects/unlicensed.html.

6 The Mechanism Design Problem

6.1 Provision Points and "Free Riding"

There are several reasons why a market may fail to allocate different license regimes to blocks of spectrum in an efficient manner. One general source of market failure is the unwillingness of bidders to reveal the true value they place on a particular license regime.[23] A major cause of under revelation in the current example is free riding behavior involving unlicensed operations. The economics are straightforward. Spectrum designated to unlicensed operations provides an alternative means by which users can access the Internet. Unlicensed use makes it possible for Internet users and entities (e.g., Google, Microsoft, Yahoo) that wish to sell access to such users to advertisers to do so without the possibility of paying a fee to an intermediary (e.g., Verizon, Comcast). Because of the common pool resource nature of spectrum designated to unlicensed use, the benefit that a given firm receives from expending the effort to avoid such a fee extends to every U-Type firm. The ability of a given firm to benefit from the actions of another firm introduces a public good aspect to the economic problem. In the current context, although it is in every U-Type firm's interest to have spectrum designated to unlicensed use, any individual U-Type firm has an incentive to "free ride" off the bids of others bidders in an attempt to maximize its own profits. If a significant number of U-Type firms elect to free ride, then the efficient designation of spectrum to licensed and unlicensed operations may not occur.[24]

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[23] Although not unique to this problem, there are other reasons why a market may "fail." One reason is the existence of non-competitive prices in the retail service market. The price signals generated by a market reflect the willingness of buyers and sellers to complete a trade. If the expressed willingness to trade is the result of competitive forces, the price signals generated in the market will themselves be competitive and will, thus, efficiently allocate resources. One instance where the willingness to trade is too high is when a buyer wishes to acquire an asset, in part, because it wishes to avoid having the asset employed by a competitor. In this instance, the willingness of the buyer to trade, as measured by the value the buyer places on the asset, is inefficiently high. This reasoning points to a possible inefficiency in the use of market forces to guide the licensing rule determination process. In particular, if the value that L-Type bidders place on spectrum is driven largely by the profits they would earn from not having the spectrum in the hands of a competitor, an auction outcome that relies on market prices to guide the licensing rule determination process may not lead to the efficient outcome.

There are several possible solutions to the problem. One solution involves preventing L-Type bidders from participating in the market process. This can be achieved by establishing a spectrum cap that limits the amount of spectrum each licensee may own in a given geographic area. Another approach involves allowing the firm to participate in the market, but discounting the firm's bid by an amount equal to the value the firm places on owning the asset for purely anticompetitive reasons.

[24] Notwithstanding the public good aspect to spectrum acquisition costs for unlicensed bidders, these bidders may also compete with each other for retail customers.

In many public good problems, free riding behavior is a *dominant strategy*.[25] In particular, it is welfare maximizing for the firm or agent to refrain from engaging in behavior that promotes the welfare of the group *independent* of the behavior of the other firms. This is so because the cost of contributing to the welfare of the group always exceeds the private benefit from doing so.[26] In the current public good problem, however, it is not a dominant strategy for any one U-Type firm to always "free-ride" off a U-Type bidder's efforts to have a given band of spectrum allocated to unlicensed use.[27]

One distinguishing feature of the current problem is the existence of a "provision point."[28] A provision point is the minimum aggregate contribution users must collectively make in order for any given user to obtain value from his/her contribution.[29] In the current context, in order for a single block of spectrum to be designated to unlicensed operations, the sum of the bids submitted by U-Type bidders must exceed the lowest bid submitted by the L-Type bidders. This bid represents for U-Type bidders the provision point for that first block of spectrum. Importantly, the provision point represents a Nash equilibrium since any unilateral deviation below the provision point value is unprofitable for the contributors.

The likelihood that an equilibrium without significant free riding will be achieved is increased as a result of the so-called "give back" option at work in the current economic environment. In a typical public good problem, a player's payoff is often reduced by the amount of his/her contribution, independently of whether other parties have made a contribution. In the current example, a contribution by the U-Type bidder only reduces his/her payoff if the sum of the U-Type bids exceeds the provision point. A similar effect is achieved when organizations

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[25] The classic example of an inefficient dominant strategy equilibrium is the "prisoners' dilemma," in which each prisoner has an incentive to confess even though their combined welfare is maximized if neither confesses.
[26] A variety of experimental studies have shown that even in instances where, according to game theory, free riding behavior is a dominant strategy, individuals fail to behave in such a manner. See Marwell, G., and R. Ames (1979), "Experiments on the Provision of Public Goods: Resources Interest, Group Size, and the Free-Rider Problem," *American Journal of Sociology* 84(6):1335-60, Isaac, M, J. Walker, J., and S. Thomas, "Divergent Evidence on Free Riding: An Experimental Examination of Possible Explanations," *Public Choice* 43(1):113-49.
[27] In this case, the public good problem is more closely related to two other well known game situations. In the game of "chicken" both players want to follow aggressive strategies as long as their opponent is expected to be passive. Nevertheless, the equilibrium outcomes call for only one, but not both of the players to be aggressive. In a somewhat different game known as the "battle of the sexes", one player wishes to attend an event (e.g. a boxing match) and the other player wisher to attend a different event (e.g. a ballet). In spite of these preferences, both players would rather go to the same event rather than different ones. In both "chicken" and "battle of the sexes" there are multiple Nash equilibria, which are welfare superior to the "free riding" equilibrium which also exits in these cases.
[28] The role of a provision point in public good problems is discussed in detail by John Ledyard, "Public Goods: A Survey of Experimental Research," in *Handbook of Experimental Economics*, edited by J. Kagel and A. Roth, Princeton University Press 1995.
[29] Marwell and Ames (1979) were the first to introduce the notion of a provision point in a public good experiment.

conduct fund drives under the rule that the public good will not be provided unless a certain minimum level of funding is achieved. By reducing a U-Type bidder's risk of making a contribution, the give back option can be expected to increase the contributions made by such bidders.[30] However, the give back option and provision point features may not always lead to the efficient outcome. Both features give rise to multiple Nash equilibria when participants need contribute only a portion of the value they place on having a public good provided. The existence of multiple equilibria may create an important coordination problem because participants will typically have differing equilibrium preferences.[31] The non-dominance of a pure free–riding behavior and the existence of multiple equilibria can be demonstrated using the parameters included in the Session 1 experimental set-up (reproduced in Table 1 below).

6.2 Nash Equilibria

Economic theory predicts that, at a minimum, participants in a mechanism design problem will rationally select bidding strategies that are sustainable as Nash equilibrium outcomes. In the context of a spectrum auction, a Nash equilibrium represents a set of bidding strategies such that no bidder can expect to increase his or her payoff by following a different bidding strategy, assuming that every other bidder continues to play their equilibrium strategy. In the absence of a strictly dominant strategy for each bidder, there can in general be a large number of Nash equilibria. A full description of these equilibria depends on a detailed description of the information available to each bidder about the auction mechanism itself and each bidder's beliefs about the private valuations of all rival bidders. In a set of auction experiments to be described later, experimental subjects were told the rules of the auction and their individual assigned valuations, but were given no information about other subject's valuations other than the total number of subjects participating. Suppose, contrary to this experimental setup, that each bidder has complete information about the number of other bidders, the type (i.e. licensed/unlicensed) of each bidder, and each bidder's true valuation. In the remainder of this section we will show that under these assumptions it is possible to enumerate the full set of Nash equilibrium outcomes.

[30] Experimental evidence indicates that the "give back" option has the effect of increasing contribution rates in some public good environments. See Isaac, M, D. Schmidtz, and J. Walker (1989) "The Assurance Problem in a Laboratory Market," *Public Choice*, 62, 217-236.

[31] See Isaac, Schmidtz, and Walker (1989) *op cit*.

In the experiments, the auction was conducted as a particular type of "clock auction" as described above. The tested clock auction can be shown to be strategically equivalent to a sealed bid auction in which each bidder submits two bids – one for the first unit of spectrum acquired and a different bid for the second unit. In the experimental set up, the clock price started at 10 and advanced in units of 10. In order to simplify the present analysis it will be assumed that bids can be submitted in any integer units, so that the minimum bid increment is equal to 1. As in the experiment, the market clearing price is equal to either the highest rejected bid for licensed use or the highest rejected aggregate bid for unlicensed use, whichever is the highest. Winning licensed bidders pay this price, while each winning unlicensed bidder pays an amount proportional to his actual bid, such that the sum of the unlicensed prices add up to the market clearing price. The values assigned in Session 1 of the experiments are shown in Figure 2 above and Table 1 below.

Table 1: Assigned Valuations in Session 1 of the Experiment

Bidder	Subject Type (L/U)	Value Unit 1	Value Unit 2
A	L	400	250
B	L	300	200
C	U	120	80
D	U	120	80
E	U	60	40
F	U	60	40
G	U	40	20
H	U	40	20
Sum C – H		440	280

Assuming complete information, there are a large number of Nash equilibria in the auction game, one of which is shown in Table 2. In this equilibrium, licensed bidders submit winning bids for three of the four licenses, and the remaining block of spectrum is awarded to unlicensed bidders collectively. The market price is determined by the highest rejected bid, which in this case is made by both licensed bidder B and collectively by unlicensed bidders C through H.[32]

[32] We will demonstrate later that the efficient allocation cannot be sustained as a Nash equilibrium if all bidders bid their true values. However, it will also be shown that the efficient allocation can be sustained as an equilibrium with different bidding strategies.

Table 2: An Example of Nash Equilibrium

Bidder	Bid 1	Bid 2	Price	Surplus
A	400	250	200	250
B	300	200	200	100
C	56	55	55.72	64.28
D	55	55	54.73	65.27
E	27	27	26.87	33.13
F	27	27	26.87	33.13
G	18	18	17.91	22.09
H	18	18	17.91	22.09
Sum C – H	201	200	200	240

To verify that the bidding strategies shown in Table 2 represent a Nash equilibrium, one needs to show that no bidder can unilaterally benefit by changing either one of its bids. Given the bids in Table 2, bidder A wins 2 units; bidder B wins 1 unit; and the unlicensed bidders together win 1 unit. Bidder B's bid for a second unit and the combined bids of bidders C – H for a second unit tie as extra-marginal (rejected) bids equal to 200. These bids establish the market clearing price. No winning bidder can gain by either increasing its bid for the *first* unit of spectrum (since it is already winning and the market price is determined by the tie bids for a *second* unit of spectrum) or reducing his/her bid for that unit (since each bidder gets positive surplus for each unit won, and reducing a bid can only result in the loss of that surplus). If bidder B increases its bid for the second unit to 202 or greater, it will become a winning bidder, but it will have bid above its true valuation, and will therefore be worse off.[33] Since bidder B's second bid is tied with the second aggregate bid of C – H, bidder B cannot change the market price by reducing its bid for a second unit of spectrum, and therefore cannot increase the surplus attained for the first unit.

None of the unlicensed bidders C – H can benefit by unilaterally reducing their bid for the *first* unit of spectrum, since doing so would convert their collective bid into a losing bid (or tie for losing) which would result in forfeiting the surplus each bidder obtains. Similarly, none of the unlicensed bidders C – H can benefit by unilaterally increasing their bid for a *second* unit of spectrum. In order to displace bidder A's winning bid for a second unit and, in so doing, obtain a second block of spectrum for unlicensed designation, the unlicensed bidders must increase their aggregate bid to 251 or more. Such a bid would increase the market clearing price to 250,

[33] If B bids 201 for a second unit it will win with a 50% probability assuming that ties are settled by a coin toss, and this will also result in a loss of surplus.

thereby reducing by 50 the surplus that any individual bidder obtains on their first block of spectrum. This reduction in surplus exceeds the 30 units of surplus (i.e., 280 – 250) such bidders collectively would obtain from having a second block of spectrum designated to unlicensed operations.

There are a large number of Nash equilibria for the auction game described in Table 1. These equilibria can be sorted into three different "Types" according to the number of blocks of spectrum which are won collectively by the unlicensed bidders. A "Type 1" equilibrium, as represented in Table 2, results in three blocks of spectrum being designated to licensed operations and one block to unlicensed operations. While their quantitative bids may differ significantly, all Type 1 equilibrium strategies have the following characteristics.

1. Bidder A bids an amount for both units 1 and 2 of spectrum that is large enough such that no unlicensed bidder has an incentive to raise his/her bid for a second unit.
2. Bidder B bids an amount for the first unit that is large enough such that no unlicensed bidder has an incentive to raise his/her bid for a second unit. Bidder B bids exactly 200 for the second unit.
3. The six unlicensed bidders place bids for a first unit that sum to exactly 201, and bids for a second unit that sum to exactly 200. [34]
4. Total surplus for licensed bidders A and B is 250 and 100 respectively. Collective total surplus for bidders C through H is equal to 240.
5. Auction revenue is equal to 800 (i.e., 4 x 200).
6. Total surplus is equal to 1390.

In a Type 2 Nash equilibrium, the two licensed bidders win all four blocks of available spectrum. In this case, each of the unlicensed bidders individually attempts to free ride, with the result that no spectrum is allocated to their use in spite of their high collective value for it. Suppose, for example, that each unlicensed bidder places a bid equal to zero. The licensed bidders could then place any bids greater than or equal to 120 (the highest valuation of an

[34] Since bidder B and the unlicensed bidders C – H both win one unit of spectrum, the market price is determined by the higher of their bids for the second unit. If these bids are not identical, then the bidder placing the higher bid would prefer to reduce that bid by a small amount in order to reduce the market price. If these bids are equal and less than 200, it follows that any unlicensed bidder could have increased surplus by reducing its bid for their first unit of spectrum, and bidder B could also benefit by increasing her bid for the second unit to any amount less than 200. The smallest possible equilibrium bids by A and B in an equilibrium depend on the particular equilibrium bids of C – H for the second unit. If bidders C – H bid as shown in Table 2, then a simple algebraic argument shows each of these bids must be greater than 225 in order to prevent the highest value unlicensed bidders (C and D) from unilaterally increasing their bids in order to gain a second unit of spectrum for unlicensed use.

unlicensed bidder for a unit of spectrum) for both units of spectrum that they desire. In this case, the market price would be equal to zero, and no licensed or unlicensed bidder could unilaterally increase their surplus by changing their bid. As in the case of Type 1 equilibria, there are an large number of Type 2 equilibria, which all have the following characteristics.

1. Bidders C – H collectively bid an amount less that 200 (bidder B's value for a second unit of spectrum) for each unit of spectrum. The losing bid for the first unit of spectrum determines the market price.
2. Bidders A and B bid an amount for both units of spectrum that is high enough to make it unprofitable for an unlicensed bidder to bid for a second unit.
3. Total surplus for licensed bidder A is 650 minus twice the market price, while total surplus for bidder B is 500 minus twice the market price. Collective total surplus for bidders C through H is equal to 0.
4. Auction revenue is equal to the highest collective bid of C – H multiplied by 4.
5. Total surplus is equal to 1150.

Finally, there exist Type 3 Nash equilibria which sustain the efficient allocation. That is, the two licensed bidders each win one block of spectrum, and two blocks of spectrum are designated to unlicensed operations. Unlike Type 1 and Type 2 equilibria, Type 3 equilibria *require* that some bidders bid above their true valuations.[35] As an example, suppose that bidders A and B bid their true valuations for the first unit of spectrum, and that both bid 250 for the second unit of spectrum, which is equal to A's true value and greater than B's true value. Suppose in addition that the unlicensed bidders collectively bid 251 for both units of spectrum, with each bidder

[35] Suppose that unlicensed bidders C through H place winning bids for two units of spectrum and that the remaining two units are both won by licensed bidder A at bids less than or equal to A's true value. Then bidder B must have placed bids such that the market price is less than or equal to 250 (bidder A's value for the second unit). It then follows that the collective bids of C – H for both winning units must also be less than or equal to 251, since individually each bidder has an incentive to reduce its bid in order to reduce its share of the market price as long is the collective bid is still winning. But now, bidder B would prefer to increase its bid for the first unit to any amount greater than 251, which would allow B to win that unit at a market price that would remain less than or equal to 251.

Now suppose that bidders A and B each win exactly one unit of spectrum. In this case, A and B must place identical bids for their second unit of spectrum, since otherwise, the bidder placing the higher bid would prefer to lower that bid in order to reduce the market price (and increase the surplus on the winning bid for the first unit of spectrum). If all bids are less than or equal to true values, the resulting market price must be less than or equal to 200. As before, the unlicensed bidders must collectively bid an amount less than or equal to 201. In this case, bidder A would prefer to increase its bid to anything greater than 201, which would allow it to win a second unit at a market price less than or equal to 201.

bidding less than or equal to his or her value.[36] Given these bids, neither A nor B would want to increase their bid for a second unit to an amount greater than 251, since doing so would result in winning at a market price greater than either bidder's value. Similarly, neither A nor B can benefit by unilaterally reducing their bid for a second unit, since doing so would not change the market price. While these bids formally represent a Nash equilibrium, we note that we can find no compelling reason to believe that bidders A and B would choose to place bids for a second unit of spectrum in this manner.[37]

All Type 3 equilibria have the following characteristics.

1. Bidders A and B bid any amount greater than 250 for the first unit of spectrum.
2. Bidders A and B place identical bids less than or equal to 250 for the second unit of spectrum. These bids determine the market price.
3. Bidders C through H collectively bid any amount greater than 250 for both units of spectrum.
4. Total surplus for bidder A is 400 minus the market price and for bidder B is 300 minus the market price. Collective total surplus for bidders C – H is equal to 720 minus twice the market price.
5. Auction revenue is equal to the market price multiplied by 4.
6. Total surplus is equal to 1420.

While each type of equilibrium permits a large number of equilibrium bidding strategies, the total surplus and the surplus for each bidder depend only on the bids of the extra-marginal bidders which determine the market price. These results are summarized in Table 4.

[36] This is possible since the values for the second unit sum to 280.

[37] It can be demonstrated that any strategy in which a player bids above her value is weakly dominated by an alternative strategy in which the bid is equal to the value. Weakly dominated strategies cannot be eliminated as equilibrium outcomes, but they are in some cases rejected by a process of iterative elimination of dominated strategies.

Table 4: Summary Results of Nash Equiliria for Session 1 Valuations

	Market Price (P)	A Surplus	B Surplus	C – H Surplus	Total Surplus
Type 1	200	250	100	240	1390
Type 2	P < 200	650 – 2 P	500 – 2 P	0	1150
Type 3	P ≥ 250	400 – P	300 – P	720 – 2 P	1420

Given the substantial difference in total surplus across the three equilibrium types, an important question is which equilibrium type market participants will settle on. Note that licensed bidders A and B unambiguously prefer Type 2 equilibria while unlicensed bidders C – H unambiguously prefer Type 1 equilibria.[38] Nevertheless, game theory does not shed light on which type of equilibrium is most likely. In the following section we examine the equilibrium outcomes selected by market participants in two different experimental environments.

7 Economic Experiments

A series of 34 separate auction experiments were conducted, 13 of which were conducted under the Session One valuation set, while 21 were conducted under the Session Two valuation set. The information that subjects had regarding the economic environment was limited. Each of the subjects knew their own valuations, the total number of subjects in the experiment, the total number of available blocks of spectrum and that each subject had a demand for exactly two blocks. Subjects were unaware of the number of participants that preferred licensed versus unlicensed use, as well as the value each subject placed on having one or two blocks of spectrum designated to a given license regime.

To induce behavior reminiscent of the naturally occurring environment, subjects earned profits based on their performance in the experiment. In particular, subjects were paid an amount that is equal to the difference between the value they placed on having spectrum allocated to their preferred use minus the price they paid to access spectrum on that basis. Therefore, continuing the example of section 5.2 (which assumes truthful bidding), Bidder C would earn 51.8 (i.e., 120-68.2) from having one block of spectrum designated to unlicensed operations, and would earn an additional 8.6 (i.e., 80 – 71.4) from having a second block of spectrum allocated to unlicensed operations. Importantly, in the experimental framework, a U-Type bidder has the option to bid less than his or her value, or even to not submit a bid in the

[38] No bidder prefers a Type 3 equilibrium. Auction revenue and total surplus are highest in this type.

auction, deciding instead to simply free-ride off the bids submitted by other U-Type bidders. In such a circumstance, if the spectrum is allocated to unlicensed operations, the bidder is not allocated a cost share and thus, earns an amount equal to his/her assigned valuation for that spectrum block.

The experimental results reveal that the Type 1 equilibria are approximately attained in a large number of experimental sessions. In one session, the final experimental bids are shown in Table 5 along with the prices paid and surplus earned by each subject. While the unlicensed bidders somewhat overbid for the first unit of spectrum, by collectively bidding 260 instead of 201, in all other respects, the experimental bidding conforms exactly to a Type 1 equilibrium.

Table 5: Bids Submitted in Session 1 of the Experiment

Bidder	Bid 1	Bid 2	Price	Surplus
A	460	240	200	250
B	300	200	200	100
C	80	80	61.54	58.46
D	100	60	76.92	43.08
E	20	20	15.38	44.62
F	10	10	7.69	52.31
G	20	10	15.38	24.62
H	30	20	23.08	16.92
Sum C – H	260	200	200	240

Summary results for all experimental sessions are shown in Table 6. These results show that Type 1 equilibria were obtained in the vast majority of experimental auctions. For example, in 28 of the 34 auctions (i.e., 82%), the competitive process resulted in one spectrum block being designated to unlicensed use. In comparison, in only two out of the 34 auctions (i.e., 6%) did the competitive process lead to all four blocks being designated to licensed operations (Type 2 equilibria). Finally, in four out of the 34 auctions (i.e., 12%), two spectrum blocks were designated to unlicensed use, which was the efficient allocation.

Consistent with the observation that Session 2 valuations presented a greater coordination challenge for U-Type bidders than Session 1 valuations, U-Type bidders were always able to coordinate their bids in the Session 1 valuation environment so that at least one block of spectrum was allocated to unlicensed operations. In contrast, there were two instances in which U-Type bidders were unable to coordinate their bids under the Session 2 valuation environment so that no blocks were allocated to unlicensed operations.

Table 6: Experimental Results

	Average Efficiency	Number of Blocks Designated to Unlicensed Operations (Efficiency)			Total Number of Auctions
		0 Blocks	1 Block	2 Blocks	
Session 1	0.95	0 (.82)	11 (.98)	2 (1.0)	13
Session 2	0.95	2 (.80)	17 (.99)	2 (1.0)	21

The inability of the mechanism to achieve a higher efficiency value is due, in part, to the incentive U-Type bidders have to strategically reduce their demands for the second block of spectrum. It is well known that in instances where bidders have multi-unit demands and a simultaneous ascending-bid auction with uniform pricing is employed to allocate items, bidders can find it in their mutual interest to reduce demand in an effort to maximize their profits.[39] Such "demand reduction" would be profitable if the gain from a lower price for the buyer's "n"-infra-marginal units is greater than the profit it would earn from "n+1" infra-marginal units. In the current example, U-Type bidders would earn greater profits if they collectively failed to bid for a second block of spectrum electing, instead, to have the market generate a lower market clearing price.

The average efficiency obtained under each session valuation environment was 95%. In evaluating the performance of the market, it is important to recognize that the lower bound for the assignment efficiency is the level of efficiency obtained when zero blocks of spectrum are assigned to unlicensed operations. As shown, the efficiency of the market when zero blocks of spectrum are assigned to unlicensed operations is 82% under Session 1, and 80% under Session 2.

8 Concluding Comments

One of the more important spectrum management problems the FCC faces involves whether to designate spectrum to either licensed use or unlicensed operations. Spectrum designated to unlicensed use is made freely available for uses which comply with appropriate technical

[39] Such an effect is referred to as strategic demand reduction. For a discussion of strategic demand reduction in FCC spectrum auctions, see Weber, Robert, (1997) "Making More With Less*," Journal of Economics and Management Strategy,* Vol. 6. pgs. 529-548.

standards. Spectrum allocated to licensed use grants the owner of the license the right to exclude non-payers from using the spectrum and is generally awarded to private parties through an auction mechanism. The FCC and other regulatory bodies attempt to solve this problem through an administrative process. However, such a process has some important limitations, not the least of which is that it often is based on the reported needs of interested parties. One method of reducing the incentive that parties have to exaggerate the value they place on a given set of license rules involves creating a market for such rules in which participants bid to have their license rule needs met. By reducing the incentive that interested parties have to misrepresent their economic interests, this approach may substantially improve the efficiency of the licensing process.

We examine the feasibility of using a market mechanism (i.e., a "clock auction") to determine, based on the bids submitted by market participants for the corresponding licensing rules, the efficient allocation of a given amount of spectrum between licensed and unlicensed operations. One general source of market failure is the unwillingness of bidders to reveal the true value they place on a particular license regime. A major cause of under revelation in the current instance is "free riding" behavior involving unlicensed operations. If a significant number of bidders that wish to see spectrum designated to unlicensed operations free ride on the bids made by other similarly-interested bidders, then the efficient designation of spectrum to licensed and unlicensed operations may not occur.

This study created an economic model that was designed to stress test whether our market approach could achieve the efficient assignment of license rules to four spectrum blocks. Assuming complete information, analyses demonstrate that there are a large number of Nash equilibria in the auction game. Economic experiments were conducted to determine whether bidders had a tendency to settle on equilibria that achieve the efficient designation of spectrum to licensed and unlicensed operations. The results of the experiments show that in 28 of the 34 auctions, the competitive process resulted in one spectrum block being designated to unlicensed operations. In addition, in four of the 34 auctions (i.e., 12%), two spectrum blocks were designated to unlicensed use, which was the efficient designation. The inability of the market mechanism to achieve a higher efficiency value is due, in part, to the incentive U-Type bidders have to strategically reduce their demands for the second block of spectrum. Indeed, in the current example, U-Type bidders would earn greater profits if they collectively failed to bid for a second block of spectrum electing, instead, to have the market generate a lower market clearing price.