STRATEGIES FOR ALLOCATING RADIO FREQUENCIES: FEDERAL COMMUNICATIONS COMMISSION WIRELESS SPECTRUM AUCTIONS

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Abstract
The intensive use of wireless spectrum in communications necessitates complex allocation mechanisms for spectrum licenses. The Federal Communications Commission (FCC) uses simultaneous ascending auctions, an innovative auction mechanism, to address the complexities created by the frequencies, bandwidths and geographic locations of spectrum licenses. In this study I discuss the objectives of spectrum auctions, and analyze the strategic auction design issues faced by the FCC; including price discovery, exposure, and information disclosure problems. Finally, I analyze how the FCC addresses these issues in light of the simultaneous ascending auction mechanism, and identify areas for improvement in strategic spectrum auction design.
Key words: FCC, Radio Frequency, wireless spectrum, auction design

Introduction

The widespread use of the wireless technologies such as airline TVs, cellular phones and wireless internet brought about the intensive use of the radio spectrum, and the need to prevent interference with services using adjacent spectrum bands necessitate the organization of the market for the underlying publicly owned scarce resource: wireless spectrum. To fulfill this need, the Federal Communications Commission (FCC) has been the governing body of the wireless spectrum licenses in the United States. In the past the FCC used various mechanisms to allocate the spectrum licenses to market participants including administrative hearings and lotteries. Starting in 1994, the FCC started to use an innovative auction mechanism, simultaneous ascending auctions, based on the advice of prominent economists Paul Milgrom, Robert Wilson and Preston McAfee.[i] Since 1994 the FCC has conducted over 70 simultaneous ascending auctions, which generated revenue of approximately $52 bn. according to FCC Report (2009). [ii] Lessons learnt from these auctions will shed light on the coming Long Term Evolution (LTE) auctions throughout the world.[iii]

In this paper I provide an overview of spectrum auctions objectives, the strategic auction design issues faced by the FCC, and review how the FCC addresses these issues in light of the simultaneous ascending auction mechanism. The remainder of the paper is organized as follows. Section II reviews the structure of spectrum licenses allocated by the FCC; Section III discusses the historical context of spectrum auctions. Section IV discusses the FCC auction design objectives, and provides examples of how these objectives are (or are not) addressed by the current auction system used by the FCC. Section V concludes.

2. Understanding the Spectrum Licenses

The spectrum licenses in the US have three important dimensions: the frequencies (the location in the spectrum band), the bandwidth (size in the spectrum band) and the area type (geographic size). For example in the 700 MHz Auction (Auction 73) the FCC auctioned off spectrum in 5 frequency blocks on 4 different geographic sizes in 4 different bandwidths in 2008. Table 1 provides a summary of licenses by frequency block; and the Appendix contains the license maps of different geographic sizes.

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Table 1: FCC 700 MHz Auction (Auction 73) License Information

Block	Bandwidth	Frequencies	Area Type	Licenses
A	12 MHz	698-704 / 728-734 MHz	EA*	174
B	12 MHz	704-710 / 734-740 MHz	CMA*	734
C	22 MHz	746-757 / 776-787 MHz	REAG*	12
D	10 MHz	758-763 / 788-793 MHz	Nationwide	1
E	6 MHz	722-728 MHz	EA*	176

Source: FCC (2007).

* EA = Economic Area; CMA = Cellular Market Area; REAG = Regional Economic Area Grouping. See Appendix.

The frequencies of all licenses were clustered around the 700 MHz band. However, the bandwidths of the blocks differed: for example the A block licenses were for 12 MHz of spectrum, whereas the C Block licenses were for 22 MHz of spectrum. In addition to having different locations and sizes in the spectrum block the licenses also differ in terms of their geographic sizes. The FCC used 4 different geographic sizes: the Cellular Market Areas (CMAs) divide the US map into 734 Metropolitan Statistical Areas and Rural Service Areas; Economic Areas (EA) divide the US into 174 regions; and Regional Economic Area Groupings (REAG) divide the US into 12 regions. Finally, the Nationwide license is valid for the entire US.

The license construction scheme of FCC results in potential substitutions across different blocks. A firm that wants to serve the city of San Francisco, for example, can do so by obtaining the San Francisco-Oakland CMA (CMA-7), or the San Francisco-Oakland-San Jose EA (EA-163), or the West REAG (REAG-6), or the nationwide license. In addition to this opportunity to substitute across blocks, the FCC license structure also yields complementarities or synergies across licenses. For example a telecom company that wants to serve the Greater Bay Area, including San Francisco, Oakland and San Jose, has a few options to accomplish this goal. One option involves the acquisition of the San Francisco-Oakland CMA license and the San Jose CMA license (CMA 27) together, which implies the existence of a potential complementarity between these two licenses that cover adjacent geographic areas.[iv]

These potential complementarities and substitutions contribute to the complications faced by economists and the FCC in the design of the simultaneous ascending auctions, including the efficient allocation issue, which I investigate in detail in Section IV.

3. Spectrum Auctions: History and Objectives

The allocation of spectrum issue goes back to as early as 1910 (Coase (1959)), though the idea of using an auction to allocate spectrum licenses came much later. Herzel (1951) the first study to propose auctions as a spectrum allocation mechanism, ties the allocation question to multiple radios broadcasting on the same or close frequencies, yielding interference. To mitigate this problem, the Congress first passed the Radio Act of 1912, then the Radio Act of 1927, and the Communications Act of 1934. The Federal Radio Commission was founded with the 1927 Act to allocate radio licenses based on "public interest, convenience, or necessity." The 1934 Act replaced the Federal Radio Commission with the Federal Communications Commission. However, these acts did not solve all the controversy around the radio spectrum. Herzel (1951) describes the controversy in administrative hearing procedures regarding color television standards between Columbia Broadcasting System

(CBS) and Radio Corporation of America (RCA) during the late 40's and early 50's, and suggests that instead of choosing between the standards proposed by one company or the other, "[t]he FCC could lease channels for a stated period to the highest bidder without making any other judgment of the economic or engineering adequacy of the standards to be used by the applicant. The FCC would still determine the width of channels, but on the basis of one criterion -the maximization of revenue from the leasing of this scarce natural resource." [v] In addition to Herzel (1951), auctioning the spectrum was also supported by Coase (1959) who, just like Herzel, sees the process as a free markets issue, and notes that a market mechanism provides a more precise measure of benefit and cost.

Even though the auction system was proposed much earlier and supported by respected economists, administrative hearings and lotteries have been used in spectrum allocation until early 1990's. The developments before 1990s in game theory and understanding its applications may have also played a role in using auctions to allocate spectrum licenses. Only with the Omnibus Budget Reconciliation Act of 1993 (the `93 Act) the use of an auction system in spectrum allocation was made possible. The `93 Act first states that the prior spectrum assignment procedures can "result in an inefficient distribution of spectrum and an unjustified windfall to speculators." The '93 Act then gives the FCC the authority to "use a system of competitive bidding in the granting of licenses filed with the FCC involving the use of the electromagnetic spectrum (public airwaves)." The `93 Act further put forward the objectives of spectrum allocation, which include:

- improving "the efficiency and effectiveness of the process for granting radio spectrum,"
- facilitating "the introduction of new spectrum-based technologies and the entry of new companies into the telecommunications market,"
- giving "appropriate consideration to small businesses and minority-owned businesses in the competitive bidding process,"
- recognizing "the need to make reasonably priced mobile communications services available to businesses in rural areas."

In promoting auctions Congress also anticipated to "fairly compensate the United States taxpayers for use of a scarce natural resource."[vi]

Starting from 1994 the FCC used the simultaneous ascending auction system designed and proposed by economists Preston McAfee, Paul Milgrom and Robert Wilson. The design of the auction, which I discuss in the next section, is aimed at accomplishing the goals set forth by the `93 Act. Since then the FCC has conducted over 70 simultaneous ascending auctions, and generated revenue of approximately $52 bn. for the US treasury.[vii]

4. FCC Design Objectives

Auctions have been in use for centuries, and various auction designs have emerged over time. It has been well-documented that the outcome of an auction is sensitive to the details of the auction design,[viii] and the design choice for a given transaction should be chosen based on the objectives of the seller.[ix] In allocating radio spectrum subjected to the mandates of the `93 Act, the FCC's main objective is not maximizing the revenue of the auction. Instead, it is to ensure efficient allocation of the spectrum and rapid deployment of technologies.[x] Maximizing the auction revenue, hence fairly compensating the US taxpayers is only the secondary objective of the FCC auctions subject to the successful accomplishments of the former objectives mentioned.[xi]

In the rest of this section I first provide a brief overview of the simultaneous ascending auction rules adopted by the FCC,[xii] and investigate whether and how it addresses the auction design goals mandated by the `93 Act and other complications imposed by the market conditions.

4.1. FCC's Simultaneous Ascending Auctions (SAA): Rules of the Game

In the FCC's SAA system multiple licenses are auctioned off simultaneously in a multi-round auction process. In each round the FCC declares the minimum level of bids acceptable for licenses, and bidders submit their preferred licenses under the current prices. After each round the FCC declares a provisionally winning bidder for each license based on the received bids in that round.[xiii] The auction then moves into a new round as long as at least one license is receiving a new bid from at least one bidder. The auction ends when there is no new bid on any of the licenses in the entire auction. When the auction ends, the latest provisionally winning bidder on each license becomes the actual winner of that license.

Absent restrictions on activity, bidders would have an incentive to wait for the other bidders to reveal their preferences before truthfully bidding on the licenses they desire to acquire.[xiv] This would both help them calibrate their strategies, and also keep the price of their target licenses low. In plain words, absent restrictions on activity a bidder may start bidding for a license in later rounds, but not in initial rounds. In order to avoid this strategic behavior, one could think of mandating a rule that imposes to have been bidding for license from the first round in order to win it, for example. The SAA auction mandates a rule that is more complex in order to also ensure that bidders are not completely stuck with their initial choice. Indeed, this SAA rule may work better under the aforementioned substitutions and complementarities among the licenses. For example, if the price of a license increases too much, a firm has the flexibility to move its bid to a set of substitute licenses. Therefore, bidders are subject to an activity rule to ensure truthful participation during the auction. Each license has a bidding unit determined by the FCC based on the population and the bandwidth of the license.[xv] Prior to the auction start, bidders make upfront payments to purchase eligibility levels; and during the auction they have to be active on licenses that add up to a pre-determined percentage of their eligibility. To be active on a license in a round means either having a standing high bid on that license as a result of a bid submitted in an earlier round, or submitting a new valid bid in the current round. To illustrate, suppose a bidder with 1 million bidding units, and the auction activity rule to be 80%. To carry its eligibility to the next round the bidder needs to be active on licenses that add up to 800K bidding units. If instead the bidder prefers to bid on 400K bidding units worth of licenses, then its eligibility for the next round parallel to its activity in the current round is diminished to 500K bidding units, which is 100/80 times its activity. This adjustment can be considered as a punishment for those bidders who want to win licenses worth of their initial activity level. Therefore if a bidder intends to buy at his/her initial eligibility level, (s)he needs to stay active at or close to that level till auction ends as a bidder cannot increase its eligibility level once it is decreased due to its diminished activity in the previous round.

4.2. Efficient Allocation

One of the most important mandates of the `93 Act is increasing the efficiency of the license allocation process.[xvi] Efficiency in a single-product auction is defined as allocating the good to the bidder that value it the most.[xvii] However, the FCC usually auctions off more than one license, with potential complementarities and substitutability between these licenses, and with imprecise bidder valuations. These issues impose further constraints on the auction design, which I analyze under the price discovery, exposure, and information disclosure concerns.

4.2.1. Price Discovery: Single or multi-round auctions?

Accomplishing the goals put forward by the `93 Act requires solving further problems in the auction design process imposed by the market mechanisms. The first of these problems is price discovery. The auctioned spectrum is usually used for the deployment of new technologies and products, which, as in the case of the color TV example of Herzel (1951), is conducive to standards wars.[xviii] The new technology dimension induces uncertainty with regards to the market value (or the valuation) of the spectrum licenses. The fact that the consumer demand on the new technologies is also unknown only exacerbates the situation for the bidders.[xix] Therefore the auction mechanism needs to device a way to ensure price discovery for the bidders, hence eliminating the adverse impacts of the winner's curse threat on bidders.[xx]

In a multi round auction system the prices of licenses increase slowly from round to round. This enables bidders to infer information about other bidders' valuations of licenses. Given the slow enough pace of the auction the bidders have an opportunity to validate or calibrate their own license valuations with this new information on the market valuation levels, hence reducing the probability of winner's curse.[xxi]

4.2.2. Exposure Problems: Small or Large Licenses?

The FCC usually has multiple licenses to auction off, and as discussed in Section II, the license structure is conducive to complementarities and substitutions across licenses. Selling each license in a separate auction would hinder the level of efficiency accomplished due to these potential complementarities and substitutions between the licenses. Therefore the FCC uses the simultaneous ascending auction system to auction off all the licenses in a single auction to allow bidders switch across different licenses and spectrum blocks; hence taking advantage of these complementarities and substitution effects.

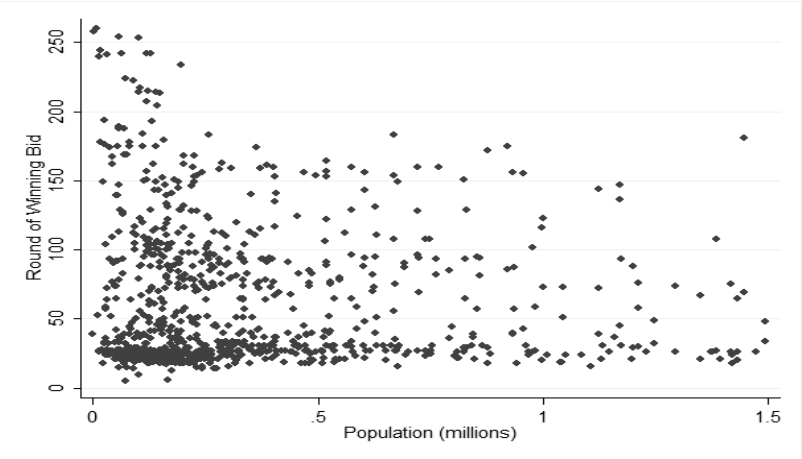
Though the simultaneous ascending auctions help in addressing the complementarities concerns, it is not able to fully solve the exposure problem faced by bidders. There may be cases in which a bidder's business plan implies an extreme case of complementarities. For example the business plan of a bidder might involve a metropolitan area license, as well as the surrounding rural area licenses, and may necessitate the acquisition of the metropolitan area license to be profitable. In such a case the value of a rural license for the bidder might plummet if the bidder fails to acquire the metropolitan area license. A bidder with such a business plan faces the so called exposure problem, and might be reluctant to bid on all the licenses (s)he desires.

In an attempt to work around the exposure problem the bidders compete on the licenses with high populations in the earlier stages of auctions, and move on to the less populated areas when the bidding activity on the former group fades away. Figure 1 plots the 700 MHz Auction license populations against the round in which the last bid on the license is received. As the figure illustrates, competition on the larger licenses tends to fade away earlier than the smaller licenses: of the 734 B-Block (CMA) licenses in the 700 MHz Auction, the 58 licenses, which has more than 500K bidding units received the latest bid in round 27 (on average). This is earlier than the 53 round average for the 676 licenses in the same block with less than 500K bidding units.

Although bidders try to strategize around the exposure issue by bidding on through the populated licenses onto smaller licenses, they may lack the sufficient extra eligibility to carry this strategy across all their target geographies due to the activity rule. In fact, Bajari and Fox (2009) study the efficiency of the 1995-1996 C-Block Auction and conclude that even though

the auction procedure creates a much higher surplus than the prior mechanisms used by the FCC, the final assignment of licenses was still inefficient. The C-Block auction used the Basic Trading Areas as the license type that divides the US into 493 licenses. They carry on counterfactual simulations and suggest that dividing the US into 4 large regional licenses (instead of 493 smaller licenses) would double the surplus captured, and that using a nationwide license would increase the captured surplus even further. The authors then state that the findings support the approach taken by many European countries in using nationwide licenses rather than smaller regions.

Figure 1: Population plot by Round of Winning Bid



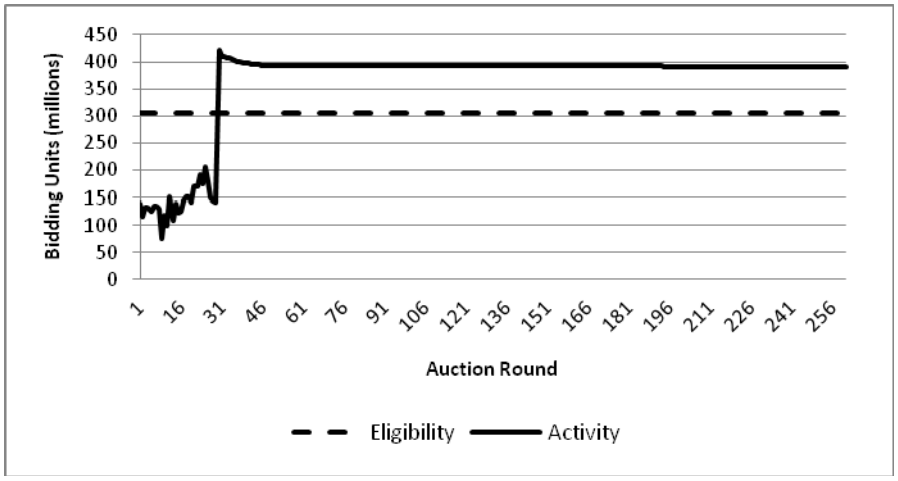
Note: The population numbers have been truncated at 1.5 million
Source: Auction 73 Results, FCC (2008).

There may be merit in using larger licenses to capture complementarities across licenses. However, using larger licenses would hinder entry of smaller regional companies. Since "entry of new companies into the telecommunications market" is one of the mandates of the `93 Act, the auction design needs to balance efficient allocation of spectrum and ensuring entry.

The use of package bidding in the 700 MHz Auction is a step by FCC towards finding this balance. Bidders were allowed to submit bids on any of the 12 individual REAG licenses in the C-Block, or one of the 3 packages: the continental US package (REAGs 1-8), the Atlantic Package (REAGs 10, 12) and the Pacific Package (REAGs 9, 11).[xxii] The provisionally winning bidder was then determined based on the comparison of the sum of high bids on individual licenses and the sum of high bids on the 3 packages. The use of packages in this auction offers a good case study to illustrate the challenges faced in auction design. Although this was a step in the right direction, the particular implementation was conducive to some anomalies, which might have adversely impacted the efficiency of the allocation process. The problem was in the calculation of the activity rule, which manifested itself in the calculation of Verizon's eligibility. In Round 29 Google Airwaves was the provisionally winning bidder on the continental C block licenses (the 50-States package). On the other hand, Verizon had the highest bids on 3 REAG licenses, but was not counted active on those licenses because the package bid was higher than the sum of individual bids. In Round 30 Verizon increased its bids on 5 REAG licenses, for which it had the eligibility to do so. As a result, the bids on the individual licenses surpassed that of the package, and Verizon became the provisionally winning bidder on all 8 licenses in the package. This increase resulted in an activity level that was more than Verizon's eligibility for the round.[xxiii] (See Figure 2). However, within the confines of the auction rules, this increase in activity above eligibility is outside the spirit of

the general auction rules though the auction design did not rule out such an instance. Hence, it undermines the credibility of the auction system.[xxiv]

Figure 2: Verizon Wireless Eligibility and Activity Levels during the 700 MHz Auction



Source: Auction 73 Results, FCC (2008).

The activity rule is only one of the complications package bidding introduces into the SAA system. To capture the efficiencies, the FCC needs to allow the bidders to decide their own packages (instead of pre-defined packages). However, in such a case the number of potential packages increases exponentially with the number of licenses in the auction,[xxv] which renders the clearing mechanisms in use moot. Cramton (2009) discusses a new system that allows the use of arbitrary packages. However, this system requires the licenses on the same geography to be substitutes making the bidders indifferent between different bands of the spectrum on the same geography. Anecdotally bidders take into account the location of spectrum in the band for a variety of reasons.[xxvi] Hence, the FCC spectrum auctions needs further improvements.

4.2.3. Information Disclosure: Open or Closed Bidding?

Information disclosure has been subject to extensive analyses in the auction and mechanism design literature.[xxvii] In the context of SAAs disclosing the identity of rival bidders and rival bid amounts are two important pieces of information that is of value to the bidders.[xxviii]

The identity of rival bidders may reveal valuable information to the bidders. For example, if a license is creating a doughnut hole among the other license holdings of the rival, then the rival is likely to increase the price to above market levels. When bidders possess this information, they may stop bidding on that license although the price is below its true valuation, in expectation that the rivalry may lead to a price war on the license. Conversely, if the rival is a budget constrained bidder, then it is likely that the price war on the license may not last for too long. Therefore, revealing bidder identities may reduce competition in the auction. On the other hand, anecdotal evidence suggests that bidders' valuations are impacted by the identity of competitors in a market. As a result, observing which bidders are winning the neighboring licenses is a piece of information for bidders in updating valuations for their target licenses. As discussed above fine-tuned valuations may enhance efficiency of the auction.

The FCC has adopted a full disclosure policy until recently, in which bidder identities and bid amounts were revealed after every auction round. In Auction 66 the FCC declared that if the level of subscription to the auction is high enough (on average three or more bidders per license), then the full disclosure policy would continue; otherwise the auction would not be

competitive enough to overcome the adverse effects of identity disclosure and only the bid amounts would be disclosed, but not the bidder identities.[xxix] The FCC used blind bidding in the 700 MHz Auction for the first time, in which bidders are not able to see the identities of other bidders before the auction ends. Bajari and Yeo (2009) discuss how these changes in information disclosure policies of the FCC have mitigated the tacit collusion, hence have improved the auction results in favor of the public.

Conclusion

The allocation of wireless spectrum has been an issue since the early 20th century, and the use of auctions in spectrum allocation has been suggested as early as 1951 (Herzel (1951)); however, the auctions have been in use only since 1994. The FCC has run more than 70 spectrum auctions generating revenue about $52 bn. for the US treasury (FCC Report (2009)) since 1994.

The ’93 Act of the Congress enabled the FCC to run the spectrum auctions, but also imposed efficiency of the allocation process as a goal. In addition, the market conditions imposed further conditions on the FCC’s auction design process. As a result, the FCC auction system is a complex one: simultaneous ascending auction. Not surprisingly, the auction rules have evolved since 1994 to incorporate the observed issues in the auction process, including the use of package bidding, introduction of different license sizes, and changes in information disclosure policy. Studies show that the evolution of the rules have mitigated the inefficiencies in spectrum allocation through auctions, such as reducing tacit collusion among the bidders through blind bidding. Nevertheless, the auction mechanism used by the FCC still needs to be improved on certain dimensions, including the need for a better designed package auction and better license geographies that balances the synergy across neighboring licenses while at the same time aiding the entry of new firms into the telecommunications market. Lessons learnt from the FCC auctions will shed light on the coming LTE auctions designs throughout the world.

References

Bajari, P. and J. Yeo (2009) "Auction design and tacit collusion in FCC spectrum auctions," **Information Economics and Policy**, 21 (2), 90-100.

Bajari, P. and J. Fox (2009) "Measuring the efficiency of an FCC spectrum auction," **NBER Working Paper Series** 11671.

Bali, T.G., K.O. Demirtas, and H. Tehranian (2008) "Aggregate earnings, firm-level earnings, and expected stock returns," **Journal of Financial and Quantitative Analysis**, 43 (3), 657-684.

Bulow, J., J. D. Levin and P. R. Milgrom (2009) "Winning play in spectrum auctions," **NBER Working Paper** Series 14765.

Camera, G., and C. Selcuk (2009) "Price dispersion with directed search," **Journal of the European Economic Association 7** (6), 1193-1224.

Coase, R. H. (1959) "The Federal Communications Commission," **Journal of Law & Economics**, 2, 1-40.

Cramton, P. (2009) "Spectrum auction design," **U. Maryland Working Paper**. URL: http://www.cramton.umd.edu/papers2005-2009/cramton-spectrum-auction-design.pdf.

Cramton, P., and J. Schwartz (2002) "Collusive bidding in the FCC spectrum auctions," **Contributions to Economic Analysis & Policy**, 1(1) URL:www.bepress.com/bejeap/contributions/vol1/iss1/art11.

Cramton, P. (1998) "The Efficiency of the FCC spectrum auctions," **Journal of Law and Economics**, 41, 727-736.

Dufwenberg, M., U. Gneezy (2002) "Information disclosure in auctions: an experiment," **Journal of Economic Behavior Organization**, 48, 431–444.

Eso, P., B. Szentes (2007) "Optimal information disclosure in auction: The handicap auction," **Review of Economic Studies, 74,** 705–731.

FCC Report (2009) Moving forward: driving investment and innovation while protecting consumers, URL: http://www.fcc.gov/fcc-moving-forward-report.pdf, Retrieved: 12.20.2010.

FCC Public Notice DA 07-4171 (2007) Auction of 700 MHz band licenses scheduled for January 24, 2008, URL: http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-07-4171A1.pdf. Retrieved 12.17.2010.

FCC (2007) Revised 700 MHz Band Plan for Commercial Services, URL: http://wireless.fcc.gov/auctions/data/bandplans/700MHzBandPlan.pdf. Retrieved: 10/23/2010.

FCC Public Notice FCC 06-47 (2006) Auction of advanced wireless services licenses scheduled for June 29, 2006, URL: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-06-47A1.pdf. Retrieved 12.17.2010.

FCC (2008) Auction 73 Results, URL: http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=73. Retrieved: 01/30/2011.

Genc, T.S. and S. Sen (2008) "An analysis of capacity and price trajectories for the Ontario electricity market using dynamic Nash equilibrium under uncertainty," **Energy Economics**, 30 (1), 173-191.

Gokpinar, B., W. J. Hopp and S. M. R. Iravani (2010) "The impact of product architecture and organization structure on efficiency and quality of complex product development," **Management Science,** 56(3), 468-484.

Hazlett, T. and R. Munoz, (2010) "What really matters in spectrum allocation design," **AEI-Brookings Joint Center for Regulatory Studies Working Paper**, 04-16.

Hendricks, K., J. Pinkse, and R. H. Porter (2003) "Empirical implications of equilibrium bidding in first-price, symmetric, common value auctions," **The Review of Economic Studies**, 70 (1), 115-145.

Herzel, L. (1998) "My 1951 color television article," **Journal of Law and Economics**, 41 (2), 523-528.

Herzel, L. (1951) "'Public interest' and the market in color television regulation," **University of Chicago Law Review**, 18, 802-16.

Klemperer, P. (2002) "What really matters in auction design," **The Journal of Economic Perspectives**, 16 (1), 169-189.

Mares, V., and R. Harstad (2003) "Private information revelation in common value auctions," **Journal of Economic Theory**, 109, 264–282.

McAfee, P. (1995) Auction design for the real world, Advanced Lectures URL: http://www.mcafee.cc/Papers/Bin/Auction.pdf>, Retrieved: 12.20.2010.

McMillan, J. (1994) "Selling spectrum rights," **Journal of Economic Perspectives**, 8, 145-162.

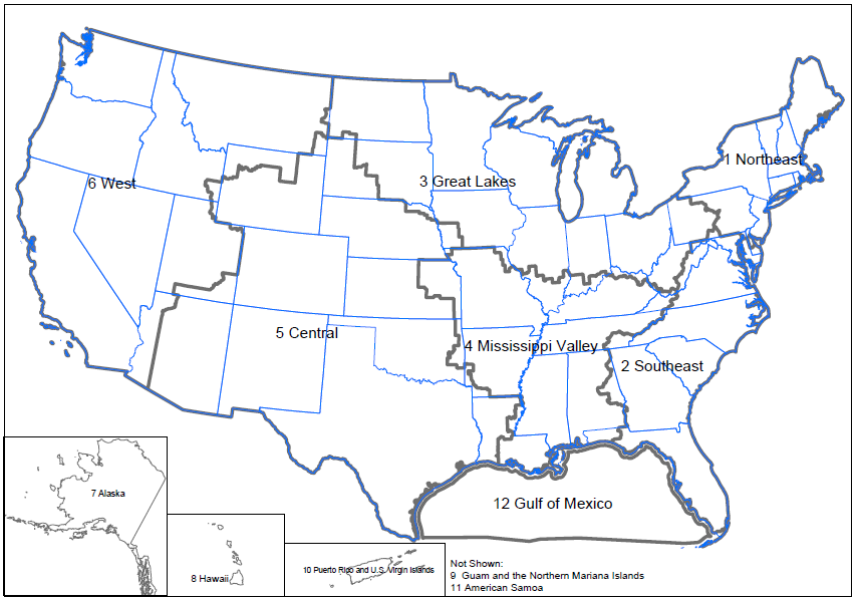
Milgrom, P. R., (2004) Putting Auction Theory to Work, Cambridge: Cambridge University Press.

Tu, Z. (2005) "Why do we use the Dutch auction to sell flowers?—Information disclosure in sequential auctions," URL: http://cedr.whu.edu.cn/cedrpaper/2007101516252.pdf.

U.S. Congress, Omnibus Budget Reconciliation Act of 1993, Conference Report [HR 2264], Title IV, Communications and Transportation, Report 94-141, (1993).

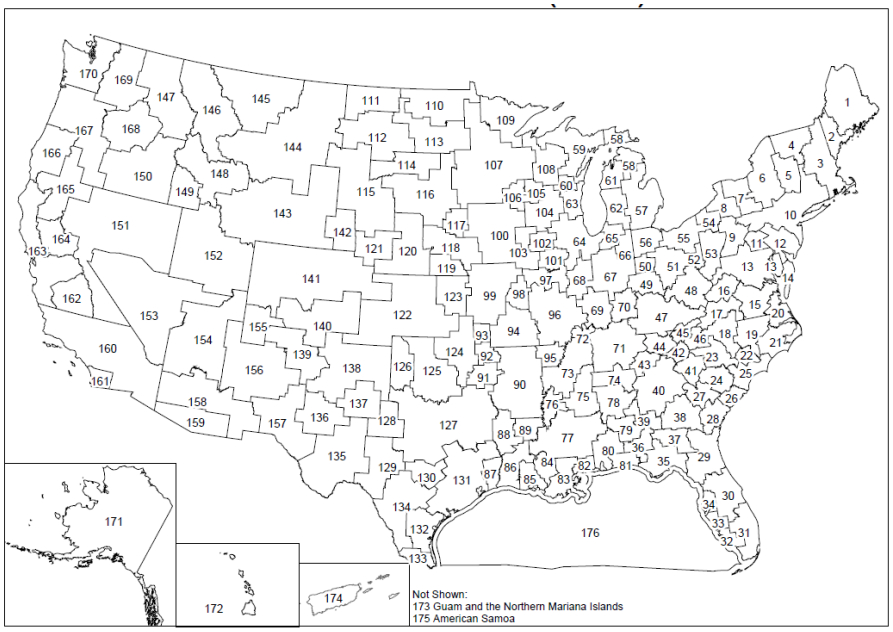
Appendix: Spectrum License Maps[xxx]

A. Regional Economic Area Groupings (REAGs)



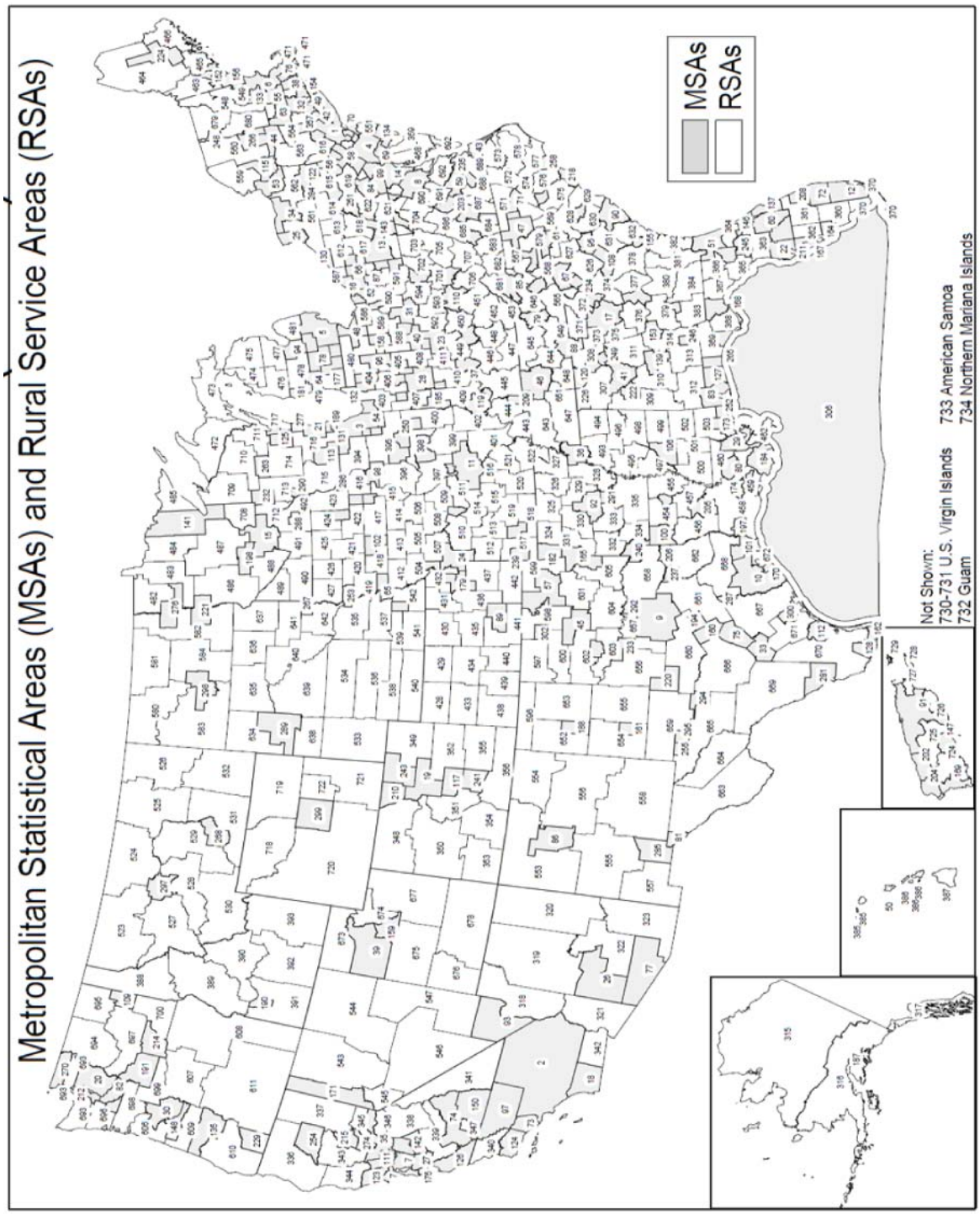
Source: FCC, http://wireless.fcc.gov/auctions/data/maps/REAG.pdf

B. Economic Areas (EAs)



Source: FCC, http://wireless.fcc.gov/auctions/data/maps/EA_GOM.pdf

C. Cellular Market Areas (CMAs)



[i] Milgrom (2004) pp. XVI.
[ii] Other countries using similar auction mechanisms to allocate radio spectrum include Canada, Mexico, Australia, New Zealand, India, Germany, the Netherlands, and the UK (Bulow et. al. (2009)).
[iii] LTE is a mobile broadband technology developed for cell phones and handheld devices providing fast internet connection. Because LTE offers significant improvements over older mobile communication standards, sometimes it is referred as 4G (fourth generation) technology.
[iv] See the Appendix for license maps based on different groupings, including REAGs, EAs and CMAs.
[v] It is interesting to read at a later note from Herzel (1998) that before writing his 1951 color TV article he mentioned his idea of "market pricing solutions for the allocation of scarce space in situations where the ownership of private property did not provide a satisfactory solution." The reaction he received was that "the idea was undemocratic, un-American, and impractical."
[vi] U.S. Congress, Omnibus Budget Reconciliation Act (1993).
[vii] FCC Report (2009).
[viii] Cramton (2002), Klemperer (2002).
[ix] McMillan (1994) and McAfee (1995) provide examples of how gaps in auction design may lead to undesired outcomes. McMillan (1994) discusses 1990 New Zealand second price spectrum auction as a cautionary tale in which no reserve price was imposed. As a result of this gap, the licenses went to the highest bidders that paid the second highest bids that were very low compared to the highest bids. (e.g. NZ$ 100.000 vs. NZ$ 6)
[x] U.S. Congress (1993). pp. 96-99.
[xi] While introducing the primary objectives, the '93 Act uses the wording: "competitive bidding should be structured to...", whereas in mentioning the fair compensation of the US taxpayers, the choice of words is "competitive bidding could..." (U.S. Congress (1993) p. 96.)
[xii] For detailed rules of various auctions see the FCC rulemaking documents; including FCC Public Notice FCC 06-47 (2006) for Auction 66 and FCC Public Notice DA 07-4171 (2007) for Auction 73.
[xiii] In case of two bidders submitting the same bid for a license the FCC uses a tiebreaking rule.
[xiv] Cramton (1998).
[xv] For example a 20 MHz EA license is worth twice the bidding units of a 10 MHz EA license of the same geographic region.
[xvi] The spectrum acquisitions can be deemed as the capacity investment of telecommunications companies, which may have product market implications. (For a discussion of capicity investment decisions on market prices in the electricity markets context, see Genc and Sen (2008).) On these lines, Hazlett and Munoz (2010) criticize the FCC by stating that the spectrum allocation process should focus on market efficiency in the product markets, not in the efficiency of the spectrum allocation process. However, this is not a concern on the auction design process, but is rather a rulemaking issue that only the auctioneer can address.
[xvii] For a discussion of efficiency in spectrum auctions see Bajari, Fox (2009), and Cramton (1998).
[xviii] For a discussion of new product development, see Gokpinar et. al. (2010).
[xix] See Hendricks et. al. (2003) for a discussion of the impact of uncertainty on bidder behavior.
[xx] Another issue bidders face in this context is potential price dispersion in otherwise identical or similar licenses (up to frequency block). For a discussion of price dispersion with capacity constraint sellers and search costs, see Camera and Selcuk (2009). Value calculations under risk and uncertainty are analyzed in the finance literature. See Bali, Demirtas and Tehranian (2008).
[xxi] Bulow et. al. (2009) explains how bids in early rounds of a simultaneous ascending auction provide information on the final auction prices.
[xxii] See the Appendix for license maps based on REAGs.
[xxiii] Verizon's activity in round 30 was around 421 million, compared to an eligibility of 306 million bidding units.
[xxiv] For a detailed discussion of the activity on the packages and increase in Verizon's activity above its eligibility, see Hazlett and Munoz (2010).
[xxv] In the FCC 700 MHz auction 1109 licenses were auctioned, resulting in 21109 (approximately 10114) potential packages.
[xxvi] One of these reasons is the potential interference issues with the neighboring band, which requires an unused small frequency band between the two licenses. Owning two adjacent licenses in the spectrum band eliminates the worry about interference issues and leaving a guard band between the two licenses. This increases the effectively used portion of the spectrum, which in turn increases the valuation of the license.
[xxvii] Duwfenberg and Gneezy (2002), Eso and Szentes (2007), Mares and Harstad (2003), Tu (2005).
[xxviii] In addition, providing the bidders with pre-set bid amounts (click-box bidding) for each round can also be considered as an information disclosure issue. Cramton and Schwartz (2002) discuss the introduction of click-box bidding in Auction 16.

[xxix] The initial subscription to Auction 66 was 3.04, more than the required level of 3 for full disclosure; hence the auction was again conducted with full information disclosure. For further discussion on open bidding and blind bidding issues see FCC Public Notice FCC 06-47 (2006), and FCC Public Notice DA 07-4171 (2007), the rulemaking documents for Auction 66 and Auction 73 respectively.

[xxx] Source: FCC (2008).