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Quantifying the Factors Affecting Spectrum License Value

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Abstract

The policy world is awash with worries about spectrum shortages as demand for wireless services grows. Using data on more than 69,000 licenses from every FCC spectrum auction since 1996, this paper disentangles and quantifies major factors that differently contribute to license value. I find that, all else equal, flexible use licenses are significantly more valuable than licenses that proscribe certain uses, policy uncertainty depresses license value, and Verizon and AT&T pay more than other carriers for licenses. I also find that larger geographic definitions generally correlate with lower license values and, contrary to conventional wisdom, more bandwidth is not correlated with higher values. Finally, using auction data and information from large secondary trades, I find that spectrum prices have been increasing since the mid-2000s, though some evidence suggests that the rate of increase has been slowing.

[1] I thank Corwin Rhyan for excellent research assistance, and Dave Burstein, Coleman Bazelon, Tom Lenard, Jeff Macher, John Mayo, Giulia McHenry, Gregory Rosston, and Amy Smorodin for very helpful comments. I alone am responsible for all mistakes and opinions, and welcome additional comments.

Introduction

An explosion in wireless data transmission has led to concerns that sufficient spectrum is not available to keep up with this growth. As FCC Chairman Genachowski said, "demand for spectrum is rapidly outstripping supply."[2]

In a purely economic sense, if markets function reasonably well, demand cannot exceed supply because prices will adjust appropriately. And since its first spectrum auctions in 1994, the FCC has made great strides in using market mechanisms as the primary tool for allocating spectrum to entities that value them the most. The FCC allocates available spectrum primarily through auctions and also encourages secondary spectrum markets so that as market conditions change, spectrum can continue to be deployed in high-valued ways.

A spectrum "crisis," presumably, would therefore be reflected in rapidly rising prices. However, as Peter Cramton once remarked, "spectrum isn't like pork bellies. Pork bellies are nice."[3] That is, spectrum is not a homogenous good, and its value depends on a myriad of factors, ranging from the physical characteristics of the spectrum, to the rules governing its use, to the behavior of users of neighboring bands.

Market actors take these factors into account when they bid for spectrum licenses either in auctions or in secondary markets. Unfortunately, auctions are relatively infrequent and while secondary markets are more robust than many believe, prices paid for license transactions are rarely public except in the case of the largest transactions.[4]

As a result, it is difficult to observe spectrum prices directly and quantify either the recent "spectrum crunch" or how the different attributes of spectrum affect its value. This paper attempts to shed some light on those questions. In particular, it uses data from the FCC on all 69,000 licenses sold in spectrum auctions since 1996.

This paper does not place specific values on spectrum, *á la* Bazelon and McHenry (2012).[5] Instead, it disentangles the different attributes that make spectrum valuable. In particular, it asks how physical characteristics, institutions, demand, and technological change separately affect the value of spectrum licenses.

The analysis in this paper should help reveal which uses are relatively more valuable than others and by how much. To the extent that one use is more valuable than others, it may highlight economic gains that come from reallocating spectrum to that use or, better yet, simply removing use restrictions (other than those related to interference). If, for example, spectrum allocated to broadband services is more valuable than others, then, as Coleman Bazelon noted, "According to the Principle of Spectrum Reallocation, more licensed spectrum should be allocated to support

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[2] http://reboot.fcc.gov/blog?categoryId=840092

[3] Federal Communications Commission "Policy Statement," In the Matter of Principles for Promoting the Efficient Use of Spectrum by Encouraging the Development of Secondary Markets, Released December 1, 2000.

[4] John Mayo and Scott Wallsten, "Enabling Wireless Communications," *Information Economics and Policy* 22, no. 1 (March 2010): 61–72.

[5] Giulia McHenry and Coleman Bazelon, "Spectrum Value," in *Spectrum II* (presented at the TPRC, George Mason University, 2012), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2032213&download=yes.

mobile broadband services so long as any given band of spectrum is more valuable supporting mobile broadband services than in its current or other alternative uses."[6]

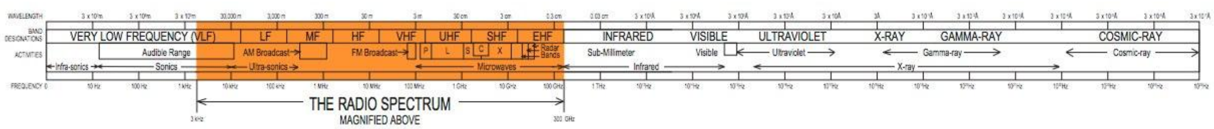
My analysis supports some commonly-held assumptions regarding spectrum valuation. For example, licenses with paired spectrum and flexible-use licenses (especially those that allow broadband) are more valuable, and policy uncertainty depresses values. Other results question conventional wisdom: in terms of price per MHz-POP, licenses that cover larger areas seem to be less valuable than licenses that cover smaller areas, and licenses with more bandwidth do not—all else equal—appear to be more valuable than others.

Finally, I find evidence that, all else equal, spectrum prices increased significantly from 2007-2011, suggesting that spectrum is, in fact, becoming increasingly scarce in a relative sense, but the rate of increase in prices appears to be slowing. The FCC and NTIA should continue to move spectrum into the market and ensure that spectrum already available be able to move smoothly and efficiently through secondary transactions.

What Makes Spectrum Valuable?

The radio spectrum, the part of the electromagnetic spectrum used for communications (Figure 1), is valuable because it is a key input into wireless services. Different bands of spectrum, however, have different physical characteristics that make them more and less appropriate for different applications. Demand for these different applications, the price of technologies that complement and substitute for spectrum, and the behavior of neighboring spectrum users underlie the value of the relevant spectrum bands. [7]

Figure 1: Spectrum from Very Low Frequency to Cosmic Ray[8]



We can usefully identify four categories of factors that affect spectrum value:

- Characteristics of the spectrum license itself, including the geography and population it covers and its frequency;

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[6] Coleman Bazelon, *Expected Receipts from Proposed Spectrum Auction* (The Brattle Group, Inc., July 28, 2011), 2; Coleman Bazelon, "Oral Testimony of Coleman Bazelon, The Brattle Group, Inc." (Testimony, U.S. House of Representatives, Committee on Energy and Commerce, Subcommittee on Communication and Technology, April 12, 2011), http://democrats.energycommerce.house.gov/sites/default/files/image_uploads/Testimony_04.12.11_Bazelon.pdf.

[7] As the FCC states, spectrum value is affected by "its location, technical characteristics, the amount of spectrum, the geographic area covered, the availability of technology suitable for a given band, the amount of spectrum already available for provision of similar services, the number of incumbents presently occupying the spectrum, and whether incumbents, if any, will remain licensed in that spectrum or will be relocated to other spectrum." Wireless Telecommunications Bureau, *The FCC Report to Congress on Spectrum Auctions* Report (Federal Communications Commission, October 9, 1997), 32–33.

[8] National Telecommunications and Information Administration, "United States Frequency Allocations: The Radio Spectrum," October 2003, http://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf.

- Underlying demand for wireless services, for which spectrum is an input;
- Institutional factors including the rules governing each license, such bandwidth size and usage rules; and
- How technological change and innovation affect the extent to which spectrum is a substitute or a complement for other inputs into wireless service provision, such as cell splitting and spectrum sharing.

Physical characteristics

Of all the factors affecting value, spectrum's physical characteristics are the only ones that cannot change. Different frequencies are better suited to different applications. Common communications technologies typically use spectrum between 200 MHz and 3 GHz.[9] Frequencies above 3 GHz, called "super high frequency" (SHF, 3 – 30 GHz) and "extremely high frequency" (EHF, above 30 GHz) tend to be used for microwave transmissions, satellite links, and services that use line-of-sight communication.[10] Within the 200 MHz – 3 GHz "sweet spot," frequencies below 1 GHz tend to be favored for their better propagation characteristics, although this advantage is smaller in areas that require more transmitters and receivers to compensate for objects that block signals, like buildings.

The geographic area covered by a spectrum license affects its value. Most importantly, the population covered affects value because it is related to potential demand for wireless services. Additionally, economic activity and income of the region covered could affect license value, as could topographical features that influence the type of infrastructure needed to make wireless services work.

Geography is also an institutional factor, since the FCC decides on the license boundaries prior to auction. The FCC has used several geographic aggregations when defining licenses.[11] Defining the geographic boundaries of licenses is necessary to conduct an auction, and based on the intended services it is possible to guess which boundaries are sensible, but it is difficult for anyone to know precisely the most efficient definitions. As a result, the FCC has used a large number of different definitions.[12]

Underlying Demand for Wireless Services

Regional population reflects potential consumers of wireless services and, thus, demand. But wireless demand is also a function of available services. Demand for wireless services is undeniably increasing, and is expected to continue to increase for the foreseeable future (see, for example, Figure 2).

[9] Nigel Laflin and Bela Dajka, "A Simple Guide to Radio Spectrum," *EBU Technical Journal* (January 2007): 8, http://www.ebu.ch/fr/technical/trev/trev_309-spectrum.pdf.
[10] Laflin and Dajka, "A Simple Guide to Radio Spectrum."
[11] A detailed list and explanations are available at the FCC http://wireless.fcc.gov/auctions/default.htm?job=maps#Geographic Licensing Schemes
[12] http://wireless.fcc.gov/auctions/default.htm?job=maps The FCC abandoned two definitions, MTAs and BTAs, due to a copyright disagreement with Rand McNally, which created the MTA and BTA definitions. http://www.gpo.gov/fdsys/pkg/FR-2001-03-15/html/01-6386.htm

Figure 2: Cisco Projection of Global Mobile Data Traffic

Source: Cisco Visual Networking Index (2013).[13]

Technological Change

Spectrum is a necessary, but not sufficient, input into wireless service provision. Wireless services also require transmitters, receivers, and other technologies to ensure that the devices stay connected and data transmissions are routed properly. They complement spectrum because higher demand, all else equal, requires more of these investments. However, they can also substitute for spectrum. More cell sites in a given area, for example, make it possible for more devices to connect to a network. Similarly, investments in technology like spectrum sharing allow any given slice of spectrum to be used more intensively.

As these technologies improve and become less costly, wireless providers will, all else equal, tend to rely on them more than on additional spectrum. The degree to which providers trade off investments in technology and infrastructure for spectrum depends on the relative prices of those inputs.

Institutions: Rules, Regulations, Auctions, and Firm Incentives

The value of a given swath of spectrum can be affected by a number of institutional features. Licenses define the rules under which spectrum can be used, and those rules affect the spectrum's value.[14] Similarly, auction rules can affect how much a provider is willing to pay for a license. There is not always a bright line between license rules and auction rules, but in general I classify license rules as those related to how the spectrum can be used, while auction rules relate to how the license is defined for the sake of conducting the auction. Additionally, each

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[13] Cisco Systems, *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017*, February 6, 2013, fig. 6, http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf. Data traffic projections, especially by those with an interest in selling equipment to handle that traffic, should be viewed cautiously. Nevertheless, few doubt that mobile data traffic will continue to increase.

[14] More accurately, the rules affect how much value can be extracted from the spectrum.

bidder faces its own unique incentives and factors affecting how it values spectrum, such as existing spectrum holdings and cheaper access to capital.

License Rules and Regulations

Sometimes the FCC imposes restrictions or conditions on licenses in order to achieve policy goals. Generally speaking, the more restrictions a license includes, the less private value it has, although the rules could make the total social value higher or lower. Coleman Bazelon, for example, estimated in 2009 that reallocating 294 MHz of spectrum designated exclusively for broadcast to flexible use would yield net benefits of $42 - $51 billion.[15]

Auction 73 in 2008, for spectrum in the 700 MHz band, provides a good example of the effects of rules.[16] The winner of the D-Block would have been required to build a network that would also be an interoperable IP network for public safety agencies.[17] This requirement reduced the private value of the license by enough that nobody bid the reserve price.

The C-Block licenses in the same auction came with an open access requirement. Crawford, Kwerel, and Levy (2008) note that the C block sold for less than other blocks because of the open access requirement but that there may have been more economically efficient ways to build the requirement into the auction design.[18]

Not all auctions have such specific requirements, but each license specifies allowed uses of the relevant spectrum.

Auction Rules

The purpose of auctions is to use market mechanisms to allow the licenses to go to the bidders who value them the most. However, the auctioneer—the FCC in this case—must still define precisely what is being auctioned and how and, as the FCC learned very early, the auction design can affect the outcome.

To facilitate the auction, the FCC typically defines the size of each license in MHz and in geographic area, trying to optimize these based on how it expects the licenses to be used.[19] The FCC also makes other decisions about licenses, such as whether they are auctioned with paired spectrum—that is, when a license includes two bands, generally one for transmitting and one for receiving.[20]

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[15] Coleman Bazelon, *The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations* Prepared for the Consumer Electronics Foundation (The Brattle Group, Inc., October 23, 2009), 19, http://www.brattle.com/_documents/uploadlibrary/upload809.pdf.

[16] http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=73

[17] Gregory Crawford, Evan Kwerel, and Jonathan Levy, "Economics at the FCC 2007-2008," October 30, 2008, http://www2.warwick.ac.uk/fac/soc/economics/staff/academic/crawford/research/researchbytopic/econatfcc.pdf.

[18] Ibid. Ford (2008) estimated that Verizon's $5 billion winning bid was about 40 percent less than a provider would have paid without the requirement. George S. Ford, "Calculating the Value of Unencumbered AWS-III Spectrum" Phoenix Center for Advanced Legal & Economic Policy Studies Perspectives, June 25, 2008.

[19] http://wireless.fcc.gov/auctions/default.htm?job=maps

[20] Coleman Bazelon, *The Economic Basis of Spectrum Value: Pairing AWS-3 with the 1755 MHz Band Is More Valuable Than Pairing It with Frequencies from the 1690 MHz Band* (The Brattle Group, Inc., April 11, 2011), http://www.brattle.com/_documents/UploadLibrary/Upload938.pdf; Federal Communications Commission,

In the very early days of the auctions, certain rules contributed to auction failures. Auction 2 in 1994 (for spectrum devoted to Interactive Video Data Services, or IVDS) and Auction 5 ending in 1996 (the PCS C Block auction) failed principally due to poor auction design. In the IVDS auction about 125 winning bidders defaulted on their bids. The spectrum itself lay mostly unused as licensees struggled to find a business case for IVDS. In the C Block auction, Nextwave bid $4 billion for a license but then declared bankruptcy, causing the spectrum to lay fallow. Three features of the auction design contributed to these failures.

First, the FCC required only very low down payments by bidders in order to participate in the auction—$500 per license in the case of IVDS.[21] As Cramton (1997) noted, "Upfront payments were only $500 per license for licenses valued in excess of one million dollars…. A large upfront payment, which serves as a deposit to ensure payment of a penalty in the event of default, provides an incentive for bidders to be well-prepared."[22]

Second, the FCC did not require winners to pay their bids at the close of the auction. While all winners had to pay 20 percent of their winning bid within five days of the auction, small businesses were allowed to pay the remaining 80 percent over five years.[23] Rosston and Kwerel (2000) noted that "for bidders with limited assets, installment payments are like an option that can be exercised (by paying the installments) if the business turns out well and declined (by declaring bankruptcy) if it turns out badly. This option value increased bids and the probability of default since with higher bids there was a greater chance that profits would not exceed the amount paid. Moreover, installment payments may have biased the assignment of licenses towards firms with the riskiest business plans because the option value would be greatest for such firms."[24]

Third, the FCC granted generous credit to all winning bidders regardless of creditworthiness. It allowed them to pay their bids over the five years at an interest rate "equal to that in effect for 5 year treasury notes on the day the license is issued."[25] Salmon (2002) argued that installment payments combined with granting prime credit terms to all winners encouraged speculation by creating incentives for companies with the riskiest business plans to submit high bids.[26]

National Broadband Plan: Connecting America (Washington, DC, March 2010), 86–87, http://www.broadband.gov/.

[21] More accurately, bidders had to make a down payment of $2500 for every five licenses in which they were interested. Federal Communications Commission, *Procedures, Terms, and Conditions [For Participating in Auction 2]*, 1994, 5, http://wireless.fcc.gov/auctions/02/releases/2_Procedures.pdf.

[22] Peter Cramton, "The FCC Spectrum Auctions: An Early Assessment," *Journal of Economics and Management Strategy* 6, no. 3 (1997): n. 2. Also see Evan Kwerel and Gregory L. Rosston, "An Insider's View of FCC Spectrum Auctions," *Journal of Regulatory Economics* 17, no. 3 (May 2000): 253–289.

[23] Federal Communications Commission, *Procedures, Terms, and Conditions [For Participating in Auction 2]*, 7.

[24] Kwerel and Rosston, "An Insider's View of FCC Spectrum Auctions," 28.

[25] Federal Communications Commission, *Procedures, Terms, and Conditions [For Participating in Auction 2]*, 10.

[26] Salmon, "Spectrum Auctions by the United States Federal Communications Commission," 13; Salmon, in note 90, cites Stiglitz and Weiss (1981), who demonstrated that credit rationing is one way to mitigate this problem, but the FCC chose not to use that approach. Joseph E. Stiglitz and Andrew Weiss, "Credit Rationing in Markets with Imperfect Information," *The American Economic Review* 71, no. 3 (June 1, 1981): 393–410.

After these failures, the FCC eliminated installment payments, requiring full payment by the winner when it receives the license.[27]

In addition to auction rules and procedures, which the FCC can set, macro-economic and policy expectations will affect bids to the extent that those expectations affect firms' projections of their future streams of revenue derived from the services they will provide on the spectrum.

Data

The FCC makes an enormous amount of data available on all 80 auctions it has conducted since 1994.[28] These data include, among other things, information about the spectrum itself and details of the licenses being auctioned including allowed services, auction details, and bidder names.[29] Table 1 shows the number of licenses on offer for each auction since 1994 and how many were sold.

[27] Peter Cramton, "Spectrum Auctions," in *Handbook of Telecommunications Economics*, ed. Martin Cave, Sumit Majumdar, and Ingo Vogelsang (Amsterdam: Elsevier Science B.V., 2002), 18.
[28] See http://www.fcc.gov/auctions
[29] Not all auctions are relevant for this analysis. For example, many TV and radio licenses are auctions for construction permits rather than for spectrum licenses, per se, and the data do not include population estimates. In particular, auctions 25, 27, 28, 32, 37, 52, 53, 54, 62, 63, 64, 68, 70, 77, 79, 80, 81, 82, 83, 84, 85, 88, and 91 are excluded because it is not possible to calculate a price per MHz-pop.

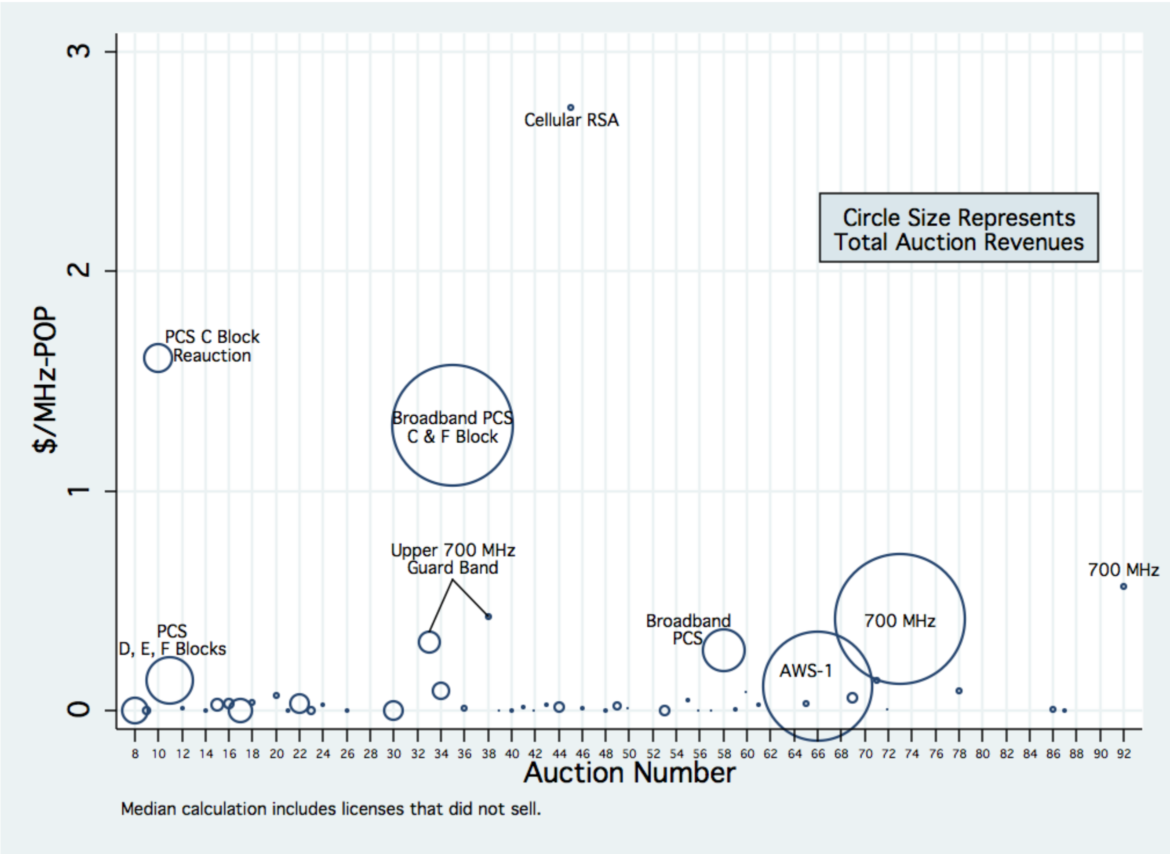
Table 1: All FCC Auctions

Auction number	Auction name	Auction end date	Number of licenses auctioned	Number licenses sold
1	Nationwide narrowband PCS	Jul-94	10	10
2	Interactive Voice and Data Services (IVDS)	Jul-94	594	594
3	Regional Narrowband (PCS)	Nov-94	30	30
4	Broadband PCS A and B block	Mar-95	99	99
5	Broadband PCS C Block	May-96	493	493
6	Multipoint/multichannel distribution systems	Mar-96	493	493
7	900 MHz Specialized Mobile Radio Service	Apr-96	1,020	1,020
8	Direct Broadcast Satellite 100 degrees	Jan-96	1	1
9	Direct Broadcast Satellite 148 degrees	Jan-96	1	1
10	Broadband PCS C Block reauction	Jul-96	18	18
11	Broadband PCS D, E, & F Block	Jan-97	1,479	1,472
12	Cellular Unserved	Jan-97	14	14
13	IVDS Phase II	Rescheduled as Auction 89		
14	Wireless Communications Service	Apr-97	128	126
15	Digital Audio Radio Service	Apr-97	2	2
16	800 MHz Specialized Mobile Radio Service	Dec-97	525	524
17	Local Multipoint Distribution System	Mar-98	986	864
18	220 MHz	Oct-98	908	693
19	General Wireless Communications Service	"Removed from auction authority"		
20	VHF Public Coast	Dec-98	48	32
21	Location and Monitoring Services	Mar-99	528	289
22	C, D, E, and F Block Broadband PCS	Apr-99	347	302
23	Local Multipoint Distribution Service	May-99	161	161
24	220 MHz	Jun-99	225	222
25	Closed broadcast	Oct-99	118	115
26	929 and 931 MHz Paging Service	Mar-00	2,499	985
27	Broadcast auction	Oct-99	1	1
28	Broadcast auction	Mar-00	2	2
30	39GHz	May-00	2,450	2,173
31	Upper 700 MHz	Folded into Auction 73		
32	New AM broadcast stations	Dec-02	3	3
33	Upper 700 MHz Guard Bands	Sep-00	104	96
34	800 MHz SMR General Category Service	Sep-00	1,053	1,030
35	C and F Block Broadband PCS	Jan-01	422	422
36	800 MHz SMR Lower 80 Channels Service	Dec-00	2,800	2,800
37	FM broadcast	Nov-04	288	258
38	Upper 700 MHz Guard Bands	Feb-01	8	8
39	VHF Public Coast and Location and Monitoring	Jun-01	257	217
40	Paging	Dec-01	15,514	15,402
41	Narrowband PCS	Oct-01	365	317
42	Multiple Address Systems Spectrum	Nov-01	5,104	878
43	Multi-Radio Service	Jan-02	27	27
44	Lower 700 MHz Band	Sep-02	740	484
45	Cellular RSA	Jun-02	3	3
46	1670-1675 MHz Band Nationwide License	Apr-03	1	1
47	Closed cellular		Cancelled	
48	Lower and Upper Paging Bands	May-03	10,202	2,832
49	Lower 700 MHz Band	Jun-03	256	251
50	Narrowband PCS	Sep-03	48	48
51	Regional Narrowband PCS [4]	Sep-03	12	12
52	Direct broadcast satellite	Jul-04	3	3
53	Multichannel Video Distribution & Data Svcs	Jan-04	214	192
54	Closed broadcast	Jul-03	4	4
55	900 MHz Specialized Mobile Radio Service	Feb-04	55	55
56	24 GHz Service	Jul-04	880	7
57	Automated Maritime Telecom Systems	Sep-04	20	10
58	Broadband PCS	Feb-05	242	217
59	Multiple Address Systems Spectrum	May-05	4,226	2,223
60	Lower 700 MHz Band	Jul-05	5	5
61	Automated Maritime Telecom Systems	Aug-05	10	10
62	FM broadcast	Jan-06	171	163
63	Multichannel Video Distribution & Data S	Dec-05	22	22
64	Full power television	Mar-06	11	10
65	800 MHz Air to Ground	Jun-06	2	2
66	Advanced Wireless Services (AWS-1)	Sep-06	1,122	1,087
67	400 MHz air-to-ground		Cancelled	
68	FM broadcast	Jan-07	9	9
69	1.4 GHz Bands	Mar-07	64	64
70	FM broadcast	Mar-07	120	111
71	Broadband PCS	May-07	38	33
72	220 MHz	Jun-07	94	76
73	700 MHz Band	Mar-08	1,098	1,090
74			Used for mock auctions	
75			never existed	
76	700 MHz Band (D-block)		Cancelled	
77	Closed cellular unserved	Jun-08	1	1
78	AWS-1 & Broadband PCS	Aug-08	55	53
79	FM broadcast	Sep-09	1	1
80	Blanco Texas Broadcast	Jul-00	1	1
81	Low power television	Sep-05	113	90
82	New analog television	Feb-02	4	4
83	FM translator		Not yet scheduled	
84	AM filing window		Not yet scheduled	
85	LPTV and TV translator digital companion channels		43	30
86	Broadband Radio Service	Oct-09	78	61
87	Lower and Upper Paging Bands	Aug-10	9,603	4,714
88	Closed broadcast		13	13
89	218-219 MHz and 220 MHz		Not yet scheduled	
90	VHF commercial television		2	2
91	FM broadcast		144	108
92	700 MHz Band	Jul-11	16	16

This analysis focuses on auctions beginning with Auction 8 for two reasons. First, the 1996 Telecommunications Act significantly changed telecommunications markets, meaning that bidder expectations in any given auction were probably much different after the Act passed. Additionally, in early auctions the FCC was still experimenting with very different auction rules, with some auctions—such as 2 and 5 discussed earlier—yielding what turned out to be abnormal results.

Figure 3 shows the median winning bids in dollars per MHz-POP for auctions since 1996. Typically, auctions yielded prices between $0.01 and $0.10 per MHz-POP, although as the figure shows, some of the larger auctions yielded higher prices. Simple summary statistics, however, mask important differences across licenses.

Figure 3: Median Winning Bids in Dollars per MHz-POP in Auctions 11-92



Instead of highlighting means and medians we want to disentangle the different elements of a license that affect spectrum value. In other words, as discussed above, the value of a spectrum license depends on the physical characteristics of the spectrum, the rules specified in the license, the available (and expected future) technologies that will make use of the spectrum, and underlying demand for wireless services. Each of these features can be quantified—some fairly precisely, and some only in ways that are not entirely satisfying. Additionally, the relevant variables do not necessarily neatly fit into a single category. Table 2 defines the variables and notes which aspects of spectrum value it measures.

Table 2: Factors Affecting License Value

		Characteristic type			
Variable	**Description**	**Physical**	**Institutional**	**Demand**	**Technological change**
Radiofrequency	3 values: frequency < 1 GHz, 1 – 3 GHz, > 3 GHz	✔			
License rules	Spectrum paired?		✔		
	Bandwidth size	✔	✔		
	Allowed uses		✔		
	Geographic area covered	✔	✔	✔	
	Population covered	✔	✔	✔	
Time	Trend and fixed effects			✔	✔

Some of these variables, such as "population covered" are self-evident, but others, especially radiofrequency and "allowed uses," require additional explanation. I divide radiofrequency into three groups—less than 1 GHz, 1 – 3 GHz, and above 3 GHz–because these commonly-used groupings reflect generally-accepted cutoffs regarding spectrum uses. Most common communications technologies use spectrum between 200 MHz and 3 GHz, so it makes sense to note which licenses are outside of that band.[30] Policy debates regarding spectrum allocation, meanwhile, often focus on spectrum below and above 1 GHz due to differing propagation characteristics, so it is sensible to attempt to determine how this difference affects valuation.[31]

Placing allowed uses into well-defined categories is not simple. The FCC lists more than 100 radio service codes on its website.[32] That number, however, is somewhat misleading because not all codes are active and any given license may have multiple service codes. The FCC's Spectrum Dashboard, by contrast, shows a much smaller number of broader categories.

The Spectrum Dashboard categorizes allowed uses in two ways: "frequency purpose (tags)" and "radio service."[33] Any given license can have multiple frequency purpose tags but only a single radio service.

Table 3 shows the number of licenses with each frequency use tag.

[30] Laflin and Dajka, "A Simple Guide to Radio Spectrum," 8.
[31] See Initial Comments of Frontline Wireless, LLC, WT Docket No. 06-150 (filed May 23rd, 2007), Exhibit 1: 12-14.
[32] http://wireless.fcc.gov/uls/index.htm?job=radio_services
[33] "Radio Service" and "Frequency Purpose" under "Advanced Search" http://reboot.fcc.gov/spectrumdashboard/searchAdvanced.seam and http://reboot.fcc.gov/spectrumdashboard/searchSpectrum.seam

Table 3: Frequency Use Tags

Frequency use tag	Number of licenses sold in auctions 1996 and later	MHz-POP of licenses sold in auctions 1996 and later (in Billions)	Amount spent on licenses sold in auction 1996 and later (in $Billions)
Broadband	6,219	86.5	$66.4
Fixed Wireless	12,629	436	67.5
Mobile Radio	30,095	58.2	53.7
Personal Use	0	-	-
Paging[34]	15,175	1.03	0.0249
Phone	11,554	81	66.8
Radar	0	-	-
Radio	645	6.82	0.439
Safety	3,594	19.9	0.221
Satellite	7	243	0.920
Television	3,773	651	21.4
TOTAL	36,670	1,060	70.3

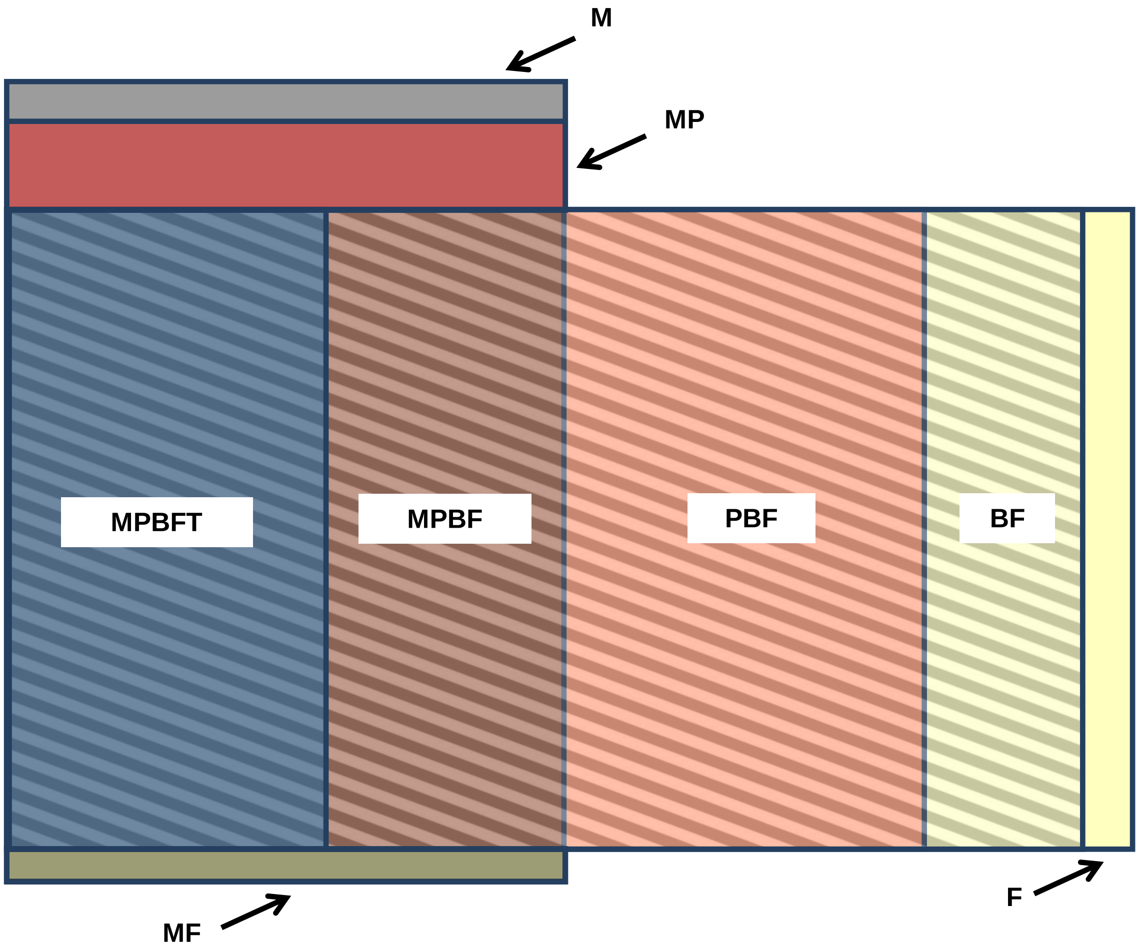
An ideal way to show license use flexibility would be a Venn diagram showing all possible intersections of use tags. We lack the resources, however, to create a Venn diagram with nine sets.[35] Instead, we show Euler diagrams, which present only a subset of possible combinations. In particular, we focus on mobile radio, phone, broadband, fixed wireless, and television frequency tags. We present this information two ways: first with the size of the rectangle indicating relative MHz-POP and again with the size of the rectangle indicating total amount spent on licenses with that combination of use tags.

We exclude licenses above 3 GHz from the figures because those licenses are in very high bands (e.g., 12 – 31 GHz) in which large bandwidth is the norm—the bandwidth of these licenses *averages* 260 MHz and ranges from 80 MHz to 1.15 GHz. While we can control for those factors in the regression analysis below, they would dominate this graphical representation and make it difficult to see information for the more policy-relevant bands below 3 GHz.

Figure 4 shows the Euler diagram for five frequency tags in MHz-POP and Figure 5 shows the diagram in total amount spent on licenses.

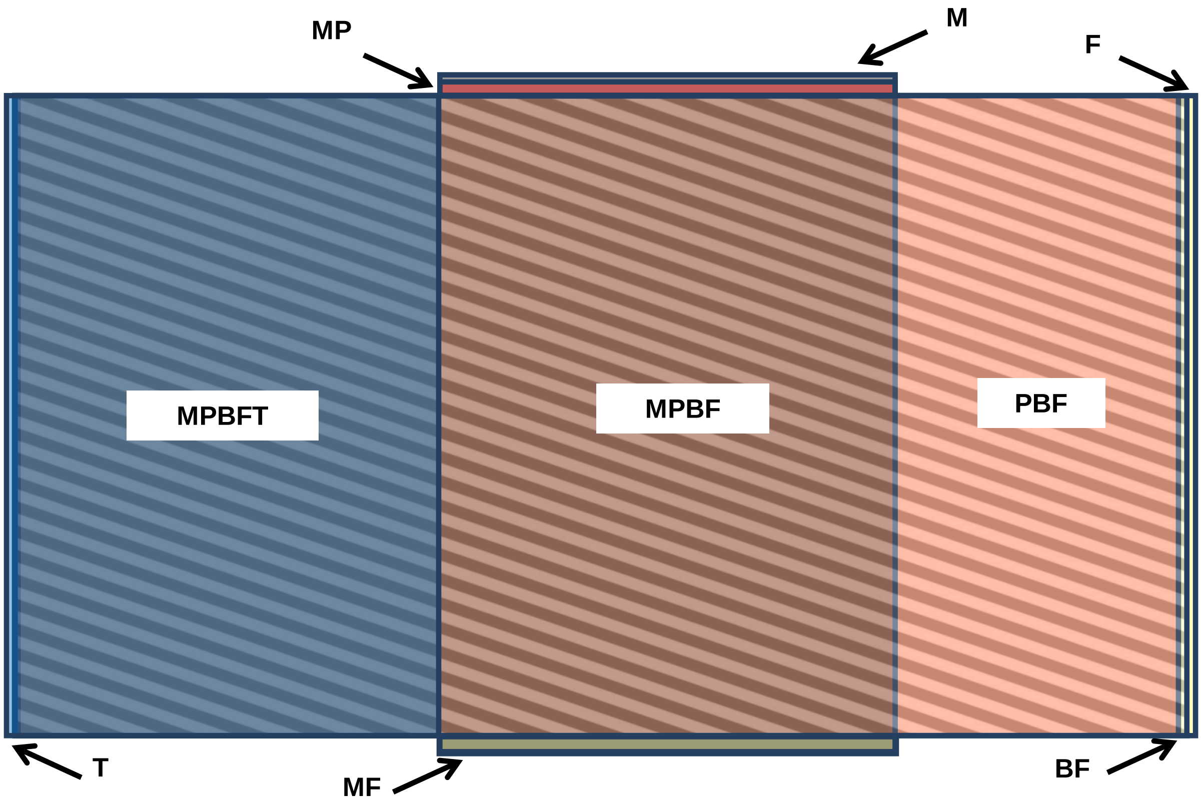
[34] The spectrum dashboard does not include paging as a frequency use tag, but including it helps to identify mobile radio in the empirical analysis because all paging licenses are also mobile radio, while not all mobile radio licenses are paging.
[35] See this site on higher-order Venn diagrams http://www.qandr.org/quentin/software/venn. As an example of how complex these diagrams can become, consider that only last year did anyone successfully create an 11-set Venn diagram Ian Steadman, "Mathematicians Grow and 11-set Venn Diagram Rose," *Wired*, August 10, 2012, http://www.wired.co.uk/news/archive/2012-08/10/11-set-venn-diagram.

Figure 4: Combinations of Frequency Tags
(Size of Rectangle Indicates Relative MHz-POPs)



B = broadband, F = fixed wireless, M = mobile radio, P = phone, T = Television

Figure 5: Combinations of Frequency Tags
(Size of rectangle Indicates Relative Total Amount Spent on Licenses)[36]



B = broadband, F = fixed wireless, M = mobile radio, P = phone, T = Television

The figures show that many licenses auctioned since 1996 allow multiple uses, especially broadband. This observation has implications for the empirical analysis. In particular, it may not be possible to identify the value of allowing broadband use, *per se*, as opposed to the value of license flexibility. I attempt to incorporate explicitly the concept of flexible use through a simple index variable, *flexibility*, which is simply the number of relevant service tags for each license.

The figures do, however, show the relative value of different license types. For example, Figure 4 shows that a comparable amount of spectrum (in MHz-POPs) was auctioned that allowed fixed but not mobile wireless and vice-versa. Figure 5, however, shows that far more money was spent on spectrum that allowed mobile wireless, while spectrum that did not allow mobile wireless was far less attractive.

Table 4 shows the distribution of the *flexibility* variable with and without paging licenses; because all paging licenses have only one tag (mobile radio), including paging skews the distribution towards less flexibility. Figure 6 illustrates how license flexibility has been changing

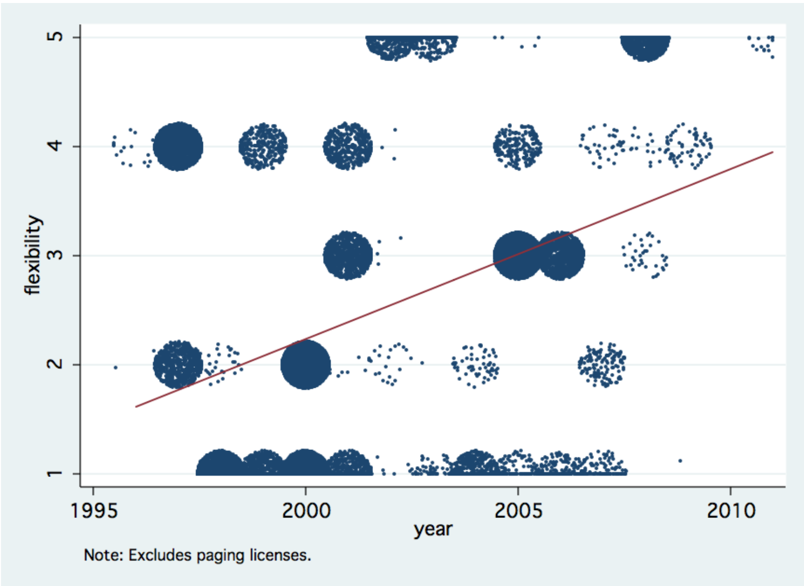
[36] "T" appears by itself in Figure 5 but not Figure 4 because of the nature of the license: we know the total amount spent on these licenses but not the population covered.

over time. The figure shows that, excluding paging licenses, the trend has been towards increased flexibility.

Table 4: Flexibility Distribution: Number of Licenses with x Frequency Tags

Number of frequency tags	All licenses	Excluding paging
1	29,944	6,011
2	4,842	4,842
3	4,227	4,227
4	2,561	2,561
5	1,846	1,846

Figure 6: License Flexibility Over Time



Such a simplistic index, however, is problematic because it implicitly assumes that each use is equally valuable. An additional approach I use, therefore, is to create a categorical variable that identifies the precise combination of allowed uses. While this approach does not allow a measure of the value of flexibility, *per se*, it makes it possible to measure the relative value of different combinations of uses.

The FCC also categorizes licenses a second way. The "radio service" categorization includes "700 MHz; 800 MHz Cellular; Advanced Wireless Service (AWS); Broadband Personal Communications Service (PCS); Broadband Radio Service (BRS) and Educational Broadband Service (EBS); 2.3 GHz Wireless Communications Service (WCS); [and] Full Power TV Broadcast and Mobile Satellite Services (MSS)."[37] However, this list omits many licenses. We therefore add additional services based on information from each auction's fact sheet. Unlike the

[37] http://reboot.fcc.gov/spectrumdashboard/searchAdvanced.seam?conversationId=3234

frequency use tags, each license can be classified with only a single radio service. As a result, interpreting some of the results of the analysis may be more complicated than when using the tags. For example, there is no single "broadband" radio service. Instead, relevant radio services include AWS-1, 700 MHz, and broadband PCS, to name a few. The Appendix lists the codes, their definitions, and how many auctioned licenses fall under each code.

Television and radio broadcasting licenses present difficulties for the empirical analysis. In particular, the geographic outlines of traditional broadcasting licenses are based on topographical contours. The FCC data therefore do not include the population covered by each broadcast license, making it difficult to calculate a price per MHz-POP.[38] This constraint means that the analysis below can account for only four auctions involving broadcast: two Direct Broadcast Satellite auctions, two Local Multipoint Distribution Service auctions, and one Multichannel Video Distribution and Data Service auction (plus the more flexible licenses that allow television broadcasting in addition to broadband and other services).

Finally, because policy and economic expectations may affect bids, I incorporate an index of policy uncertainty developed by Baker, Bloom, and Davis (2011).[39]

Empirical Analysis

With these data I can examine how the different factors contribute to spectrum license value and glean some insights into quantifying the relative scarcity of spectrum.

In principle a hedonic approach will make it possible to disentangle spectrum's different attributes, but unsold licenses present a problem. The value of an unsold license is somewhere between zero and the FCC's reservation price. Unfortunately, we cannot observe that valuation. A left-censored tobit model becomes the appropriate empirical approach.

If the FCC has a reservation price (r_i), we observe the following for the dependent variable price per MHz-pop (p_i) for a given license:

$$p_i = \begin{cases} p_i^* & \text{if} \quad p_i^* \geq r_i \\ 0 & \text{if} \quad p^* < r_i \end{cases}$$

where p_i^* is a latent variable and a function of the factors comprising the value of the license:

$$p_i^* = \mathrm{f}\begin{pmatrix} physical\ characteristics_i,\ license\ rules_i, technological\ change_t, \\ underlying\ demand_t, policy\ uncertainty_t \end{pmatrix}$$

[38] The FCC explains that it cannot "honor requests for special maps or additional service or interfering contours, or computations of area or population within these contours." http://transition.fcc.gov/mb/audio/includes/78-mapinfo.htm It is possible to download the contour shape files from the FCC and estimate the population inside them. Sadly, however, we do not have the resources to do that.

[39] Their index, they explain, "averages several components that reflect the frequency of news media references to economic policy uncertainty, the number of federal tax code provisions set to expire in future years, and the extent of forecaster disagreement over future inflation and federal government purchases." Scott R. Baker, Nicholas Bloom, and Steven J. Davis, "Measuring Policy Uncertainty," October 10, 2011. The authors make up-to-date data available at www.stanford.edu/~nbloom/policyuncertainty.zip.

I estimate two sets of regressions. The first set of regressions uses the entire sample of licenses, controlling for the different usage rules of each license. The second uses only those licenses that allow wireless broadband. In particular, the second includes auctions the FCC classified as 700 MHz, 700 MHz guard band, PCS, Cellular, or AWS-1.[40]

Empirical Results and Discussion

Table 5 shows the results of the tobit analysis. This section discusses the more noteworthy of these results.

Population

Whether analyzing all licenses or just broadband licenses, the size of the population covered by the license is positively and statistically significantly correlated with license value. At first blush this result seems sensible and intuitive since population is probably the best determinant of demand at any given point in time. Recall, however, that the dependent variable—price per MHz-pops—already incorporates population.

This result, therefore, suggests that the total price paid for a license increases more with population. If each person is worth the same amount as an actual or potential customer, then price per MHz-pop should not change regardless of the number of people. Consider, for example, two areas A and B where B has twice the population of A, and a 1 MHz license sells for $1 per MHz-pop in area A. The total price of that license would be $population(A). Assuming A and B are similar except for population we would expect price per MHz-pop to remain constant and an identical license in area B to sell for $2*population(A), since population(B) = 2*population(A).

The empirical results, however, suggest this is not the case. Instead, price per MHz-pop itself increases with population. This result is consistent with at least two (related) explanations.

First, auction participants should base their bids on the expected stream of revenues from using a given license, and these expected revenues depend not just on demand today, but on future demand. The population result suggests that, on average, winning bidders expect greater potential revenue growth in areas with larger populations. Second, larger populations likely proxy for areas with more economic activity—not simply because they have more people, but because larger groups of economic actors can create agglomeration effects.[41] So, for example, the New York metropolitan area has a Gross Domestic State Product about 13 times as large as the Kansas City metropolitan area even though its population is only about 9 times as large.[42]

[40] These categories include auctions number 10, 11, 12, 22, 33, 35, 38, 44, 45, 49, 58, 60, 66, 71, 73, 77, 78, and 92.
[41] See, for example, Bennett Harrison, Maryellen Kelley, and Jon Gant, “Innovative Firm Behavior and Local Milieu: Exploring the Intersection of Agglomeration, Firm Effects, and Technological Change,” *Economic Geography* 72, no. 3 (1996): 233–58; Michael Porter, “Competitive Advantage, Agglomeration Economies, and Regional Policy,” *International Regional Science Review* 19, no. 1 & 2 (1996): 85–94.
[42] Data for 2010 from Bureau of Economic Analysis and U.S. Census.

Table 5: Tobit Regression Results

		Dependent variable = price per MHz-pop Mean of uncensored dependent variable = 0.12 ALL LICENSES			
Population		1.39e-08*** (20.89)	1.41e-08*** (20.76)	1.41e-08*** (21.07)	1.41e-08*** (21.33)
Bandwidth in MHz		-5.22e-05** (-2.394)	-8.60e-05*** (-4.141)	-5.55e-05** (-2.549)	-4.97e-05** (-2.311)
Frequency	3+ GHz	2.806*** (12.94)	-0.429*** (-20.20)	0.170* (1.813)	-0.634*** (-3.124)
	Below 1 GHz	2.887*** (13.37)	-0.327*** (-16.74)	0.178* (1.850)	-2.530*** (-7.426)
Paired		0.195*** (37.24)	0.189*** (37.55)	0.193*** (37.17)	0.184*** (35.78)
Policy uncertainty index		-0.0149*** (-43.11)	-0.0133*** (-55.70)	-0.0155*** (-44.56)	-0.0185*** (-55.35)
Unique combinations of frequency use tags (F=fixed wireless; S=safety; P=Phone; T=Televisoin; BF excluded)	F	-3.181*** (-14.55)			
	FS	-3.020*** (-13.77)			
	Mobile Other	-2.567*** (-11.68)			
	P	-3.009*** (-13.78)			
	PBF	-0.692*** (-9.766)			
	PBFT	-3.260*** (-14.87)			
	Paging	-3.327*** (-15.24)			
	Television	-3.896*** (-15.92)			
Flexibility index			0.109*** (25.68)		
Frequency use tags	Broadband			0.480*** (5.480)	
	Fixed wireless			-0.303*** (-9.852)	
	Mobile radio			0.396*** (12.90)	
	Telephone use			-0.455*** (-19.44)	
	Safety of Like			-0.145*** (-4.636)	
	Television			-0.438*** (-7.225)	
	Paging Band			-0.775*** (-34.93)	1.816*** (6.468)
Radio service codes (BRS excluded)	Narrow band PCS				2.046*** (7.308)
	Wireless Cable Alternative				-0.103 (-0.579)
	220 MHz				2.795*** (9.912)
	700 MHz Band				1.793*** (6.412)
	700 MHz Guard Band				2.219*** (7.844)
	Coastal Communications				1.406*** (4.996)
	Multiple Address Communications				2.269*** (8.056)
	Air-Ground Communications				-0.443*** (-4.393)
	Personal Communications				2.159*** (7.688)
	Specialized Mobile Radio				4.210*** (12.16)
	Wireless Communications				-0.0955 (-0.471)
	Advanced Wireless Service				-1.313*** (-6.117)
Carrier (AT&T excluded)	Leap	-0.338*** (-10.52)	-0.354*** (-10.83)	-0.344*** (-10.70)	-0.328*** (-10.36)
	MetroPCS	0.00791 (0.0831)	-0.0185 (-0.191)	0.0161 (0.169)	0.0359 (0.383)

		Dependent variable = price per MHz-pop Mean of uncensored dependent variable = 0.44 BROADBAND ONLY LICENSES
Population		9.39e-08*** (17.84)
Bandwidth in MHz		-0.0113*** (-2.870)
Frequency		
	Below 1 GHz	1.000*** (6.085)
Paired		0.444*** (6.407)
Policy uncertainty index		-0.0780*** (-7.854)
Carrier (AT&T excluded)	Leap	-0.419*** (-6.285)
	MetroPCS	-0.531*** (-2.712)
	Other	-0.463*** (-13.30)
	Sprint	-0.101 (-1.473)
	T-Mobile	-0.279*** (-4.130)
	US Cellular	-0.499*** (-8.096)
	Verizon	-0.0113 (-0.194)
Year	1997	-1.022*** (-5.144)
	1999	-1.917*** (-10.32)
	2000	-3.453*** (-6.700)
	2001	1.134*** (5.014)
	2002	3.608*** (4.609)
	2003	1.161** (2.517)
	2005	-0.539** (-2.526)
	2006	-0.217 (-0.663)
	2007	1.718*** (3.814)
	2008	5.309*** (6.091)
	2011	17.44*** (7.245)
Region type	bea	-0.477 (-1.190)
	bta	-0.369 (-1.049)
	cma	-0.289 (-0.724)
	dma	-2.020*** (-3.397)
	mea	-0.409 (-0.813)
	mta	
	rea	-1.272*** (-3.018)
	rsa	-1.156*** (-2.666)
	nationwide	-27.47*** (-16.00)
Constant		8.353*** (8.870)
Observations		5,944

*State and Region fixed effects are included but not shown

(continued): Tobit Regression Results

Carrier (AT&T excluded) (continued)	Other	-0.449*** (-28.52)	-0.476*** (-29.73)	-0.453*** (-28.74)	-0.442*** (-28.45)
	Sprint	-0.161*** (-4.914)	-0.193*** (-5.766)	-0.162*** (-4.948)	-0.152*** (-4.706)
	T-Mobile	-0.144*** (-4.432)	-0.150*** (-4.510)	-0.151*** (-4.621)	-0.144*** (-4.491)
	US Cellular	-0.321*** (-10.97)	-0.285*** (-9.550)	-0.320*** (-10.93)	-0.334*** (-11.57)
	Verizon	0.455*** (16.59)	0.540*** (19.35)	0.452*** (16.45)	0.380*** (13.99)
Year	1997	-1.192*** (-14.00)	-1.198*** (-13.78)	-1.191*** (-13.96)	-1.169*** (-13.92)
	1998	-1.232*** (-13.99)	-0.769*** (-8.756)	-1.254*** (-14.27)	-1.363*** (-15.72)
	1999	-1.270*** (-14.74)	-1.109*** (-12.67)	-1.259*** (-14.60)	-1.407*** (-16.57)
	2000	-0.853*** (-9.952)	-0.865*** (-9.909)	-0.866*** (-10.10)	-0.789*** (-9.331)
	2001	-0.296*** (-3.423)	-0.523*** (-5.962)	-0.279*** (-3.224)	-0.0711 (-0.832)
	2002	0.478*** (4.980)	-0.0375 (-0.412)	0.548*** (5.704)	0.965*** (10.12)
	2003	0.293*** (3.258)	-0.0189 (-0.211)	0.336*** (3.732)	0.667*** (7.481)
	2004	-0.929*** (-10.29)	-1.199*** (-12.82)	-0.921*** (-10.19)	-0.936*** (-9.819)
	2005	-0.965*** (-11.21)	-1.075*** (-12.31)	-0.985*** (-11.43)	-0.981*** (-11.60)
	2006	-0.0237 (-0.221)	-0.947*** (-10.54)	-0.188** (-2.026)	0.493*** (4.489)
	2007	-0.394*** (-4.326)	-0.510*** (-5.565)	-0.362*** (-3.971)	-0.566*** (-6.305)
	2008	1.354*** (13.89)	0.719*** (7.924)	1.413*** (14.54)	1.896*** (19.57)
	2009	2.613*** (11.37)	-0.124 (-1.228)	0.949*** (8.429)	
	2010	1.509*** (15.10)	1.109*** (11.72)	1.598*** (15.96)	2.135*** (21.52)
	2011	3.652*** (23.28)	2.835*** (20.32)	3.818*** (24.28)	4.741*** (30.58)
Region type	bea	0.511*** (4.323)	-0.247** (-2.093)	0.493*** (4.194)	-2.238*** (-7.349)
	bta	1.739*** (13.00)	-0.118 (-0.983)	1.147*** (8.973)	-1.422*** (-4.160)
	cma	0.565*** (4.726)	-0.341*** (-2.847)	0.545*** (4.577)	-2.168*** (-7.119)
	dma	2.494*** (18.38)	1.194*** (9.797)	1.913*** (15.17)	-0.586* (-1.695)
	eag	0.123 (0.805)	-0.621*** (-4.006)	0.103 (0.673)	-2.569*** (-8.050)
	mea	0.573*** (4.850)	-0.281** (-2.386)	0.548*** (4.667)	-2.177*** (-7.147)
	mta	0.959*** (8.233)	0.779*** (6.565)	0.959*** (8.248)	-1.107*** (-3.691)
	rea	0.280** (2.105)	-0.661*** (-4.946)	0.234* (1.758)	-2.414*** (-7.817)
	reag	0.681*** (4.598)	-0.257* (-1.751)	0.707*** (4.836)	-2.206*** (-6.963)
	vpc	-1.250*** (-4.788)	0.102 (0.652)	0.870*** (5.250)	-3.645*** (-9.623)
	rsa	0.591*** (4.579)	-0.499*** (-3.951)	0.385*** (2.993)	-1.520*** (-4.931)
	nationwide		-2.997*** (-13.62)	-2.748*** (-12.76)	-4.795*** (-14.45)
Constant		1.801*** (11.68)	2.442*** (16.26)	1.642*** (9.666)	5.014***
Observations		63,400	63,400	63,400	63,400

*State and Region fixed effects are included but not shown

Bandwidth and Frequency

Conventional wisdom holds that more bandwidth in a given license is more valuable, since more bandwidth increases the range of services an operator can provide as well as the relative usable area since more contiguous bandwidth means fewer opportunities for interference. Yet, the results are not consistent with that view. Instead, the results suggest that, all else equal, more bandwidth is correlated with *lower* private valuations for spectrum.

One possible explanation is that despite the large number of controls, the analysis may have certain omitted variables related to allowed uses and bandwidth. For example, Auction 30 involved 100 MHz licenses in the 39 GHz band. The most valuable commercial services do not operate in that frequency, and those licenses sold for less than a penny per MHz-pop. Yet, this explanation is not especially satisfying since the result holds even for the broadband-only auctions.

Another possible explanation is that the more bandwidth a license includes, the longer it will be before the provider actually needs to "light" all of its spectrum. Under this scenario, bidders will discount the value of the spectrum based on how long it will be before they can begin to earn a return on it.

Several filings to the FCC and the Commission itself have noted that sub-1 GHz frequencies are more valuable than other frequencies.[43] The results lend weak support for that bit of conventional wisdom. Evaluating all licenses together yields no robust results on the question of frequency—the coefficients depend on the empirical specification. The results on the broadband-only analysis, however, suggest that, for broadband at least, spectrum below 1 GHz is, all else equal, more valuable than spectrum above 1 GHz.

Pairing

The analysis shows that licenses with paired spectrum are more valuable than those without, all else equal. This result is consistent with research done by Coleman Bazelon.[44] The statistically-significant correlation suggests that, all else equal and evaluated at the mean, paired spectrum is about twice as valuable in price per MHz-pop as unpaired spectrum.

Usage Rules

Not surprisingly, usage rules affect the value of licenses. Column (1) of Table 5 shows the analysis with uses categorized according to the unique combinations of frequency use tags discussed above (Figure 4). Licenses that allow broadband—especially the Broadband-Fixed Wireless combination—are the most valuable. The least valuable are licenses that allow only television broadcasting, followed by licenses that allow only paging. These results are sensible—as services are increasingly all digital and delivered over IP network it makes increasingly less sense to have spectrum devoted to specific (and dying) services.

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[43] See *Application of AT&T Inc. and Qualcomm Incorporated for Consent to Assign Licenses and Authorizations*, Order, 26 FCC Rcd 17589, (2011): paragraph 49; Comments of T-Mobile USA, Inc., WT Docket No. 12-269 (filed November 28th, 2012): 15; Initial Comments of Frontline Wireless, LLC, WT Docket No. 06-150 (filed May 23rd, 2007), Exhibit 1: 12-14.

[44] Bazelon, *The Economic Basis of Spectrum Value: Pairing AWS-3 with the 1755 MHz Band Is More Valuable Than Pairing It with Frequencies from the 1690 MHz Band*.

Intriguingly, licenses that also allow phone and television as well as broadband and fixed wireless (PBFT) are also significantly less valuable than the broadband-fixed wireless combination. This result, however, is an artifact of the empirical specification. Ninety-nine percent of the 2,193 PBFT licenses are in the 700 MHz spectrum, meaning that the sub-1 GHz indicator variable also applies.[45] The two coefficients are of similar magnitude, essentially cancelling each other out.[46]

Other specifications confirm the relatively higher value of broadband licenses. The coefficient on the broadband use tag is positive and significant, while television and safety are negative, statistically significant, and large in magnitude.

Similarly, flexibility is generally valuable. Licenses that allow broadband are generally flexible—every license (in this database) that allows broadband also allows at least one other use. The median and mean number of other uses for licenses that allow broadband is three. The analysis shows that flexibility—as measured by the number of allowed uses—is positively and significantly correlated with license value.

The coefficient on the "safety" variable shows that licenses designated for public safety have significantly lower private value than those with other uses. One should interpret this result carefully since it shows only the private value and not the net social value. It is conceivable that although public safety licenses are not worth much to private investors, their social value could be much higher.

Geographic Types

The FCC defines the geographic regions for licenses in each auction based on its expectations regarding how licenses will be used and how the regional definitions will contribute to a smooth-functioning auction. The most valuable grouping appears to be Basic Trading Areas (BTAs)[47] or Designated Market Areas (DMAs)[48], depending on the specification. The least valuable grouping is nationwide licenses. While the precise order of value by region differs by specification, regardless of specification the analysis reveals a clear negative correlation between the size of the region specified by the license and the revealed private value of the license (Figure 7).

---

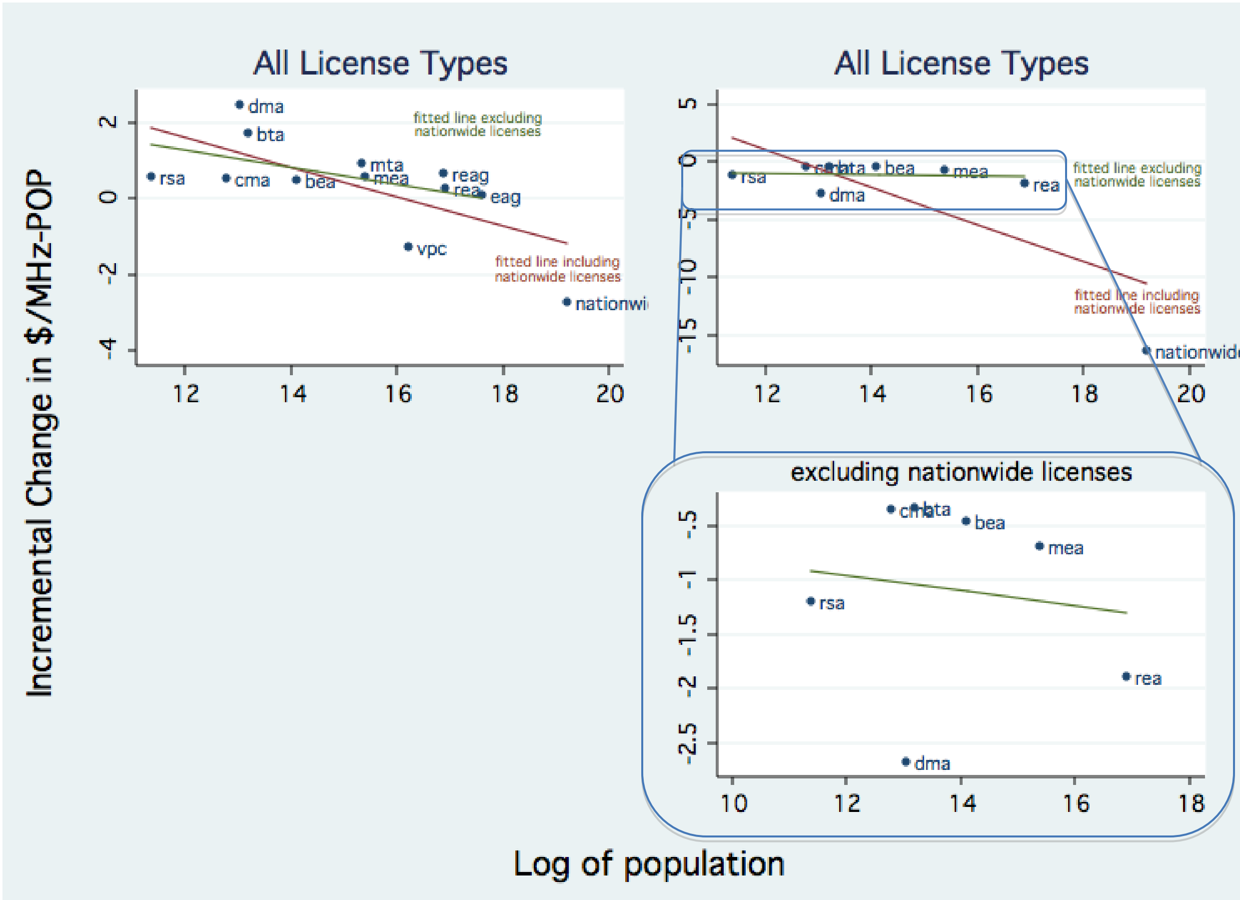
[45] The remaining 93 licenses were in Auction 86, for BRS licenses in the 1-3GHz band.

[46] The coefficient on the 3+ GHz indicator is also positive, partially cancelling out the negative effect of the television licenses, many of which were above 3 GHz. However, the magnitude of the positive coefficient on this indicator is much smaller than the magnitude of the negative coefficient on the television indicator.

[47] http://wireless.fcc.gov/auctions/data/maps/bta.pdf

[48] DMAs are generally media markets.

Figure 7: Region Size and License Value



In general, this result is understandable. Nationwide licenses include low-value areas, meaning the bidder must purchase areas in which it has little interest as well as high-value areas. Smaller geographic definitions allow bidders to more selectively bid on areas they value. As the figure shows, nationwide licenses are, by far, the least valuable, although that may be partly due to the types of services offered on those licenses to the extent that the regression does not control for those factors. Nevertheless, even excluding the nationwide coefficient a negative correlation remains between population and license value, although it is weaker.

Policy Uncertainty

The Baker, Bloom, Davis policy uncertainty index discussed earlier is negatively correlated with license value, statistically significant, and large in magnitude: each point increase in the index is correlated with a decrease in price per MHz-pop one $0.01 (for all licenses) to $0.08 (for broadband only licenses). This correlation seems improbably large given that the index ranges from 70 to 330 over this time period.

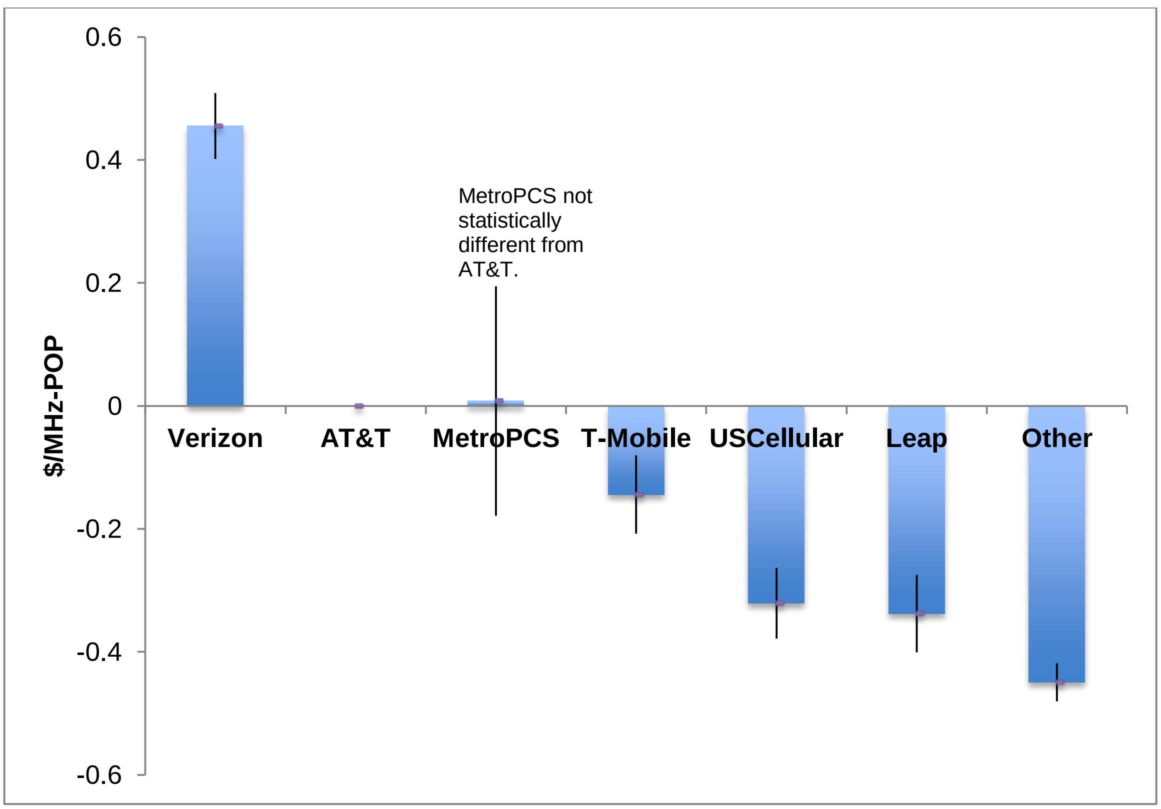
Nevertheless, the sign of the coefficient is consistent with the well-understood point that investment depends, in part, on how much investors believe that relevant rules—regardless of what they are—will remain stable. This index is based heavily on macro-economic uncertainty measures, and those are beyond the power of the FCC to affect. In addition to overall policy uncertainty, it is not too much of a stretch to believe that uncertainty regarding relevant regulations or how credibly the FCC can commit to a set of rules will also affect how much firms are willing to bid for licenses.

Carriers

In addition to common factors all bidders face such as spectrum characteristics and license rules, each bidder faces its own incentives and factors affecting how it values spectrum. For example, some may have cheaper access to capital, allowing them to bid more at relatively lower cost than rivals, while existing spectrum holdings may affect how much a given carrier values a new swath of spectrum on the auction block.

The analysis includes indicators for AT&T, Verizon, T-Mobile, Sprint, MetroPCS, Leap, US Cellular, and everyone else as a single group.[49] The analysis finds that, on average, Verizon pays more than other bidders for spectrum, with AT&T and MetroPCS paying the second-highest prices, followed by T-Mobile, US Cellular, Leap, and everyone else. Figure 8 shows these coefficient results.[50]

Figure 8: Differences in Average Prices Paid by Carrier



Note: Figure shows how much each carrier paid for licenses relative to other carriers on average, all else equal. AT&T is the baseline because it was the excluded indicator variable. Bar shows coefficient on carrier dummy variable from specification using unique frequency use-tag combinations. Line shows 95 percent confidence interval.

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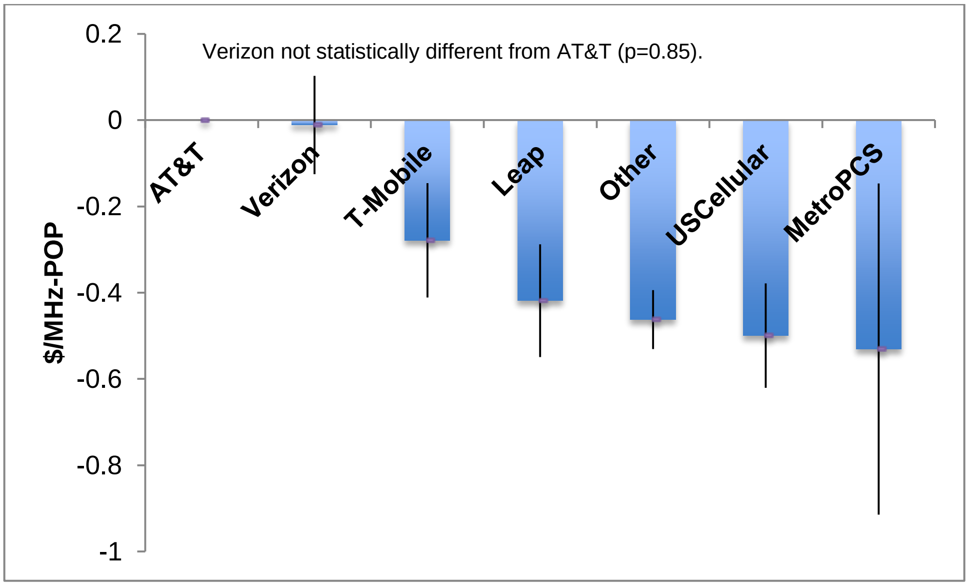
[49] Identifying the bidders is not simple. Each carrier may bid using several names due to past mergers, acquisitions, partnerships, and name changes. For example, US Cellular has bid under the name "Barat Wireless," "Carroll Wireless," and others.

[50] The figure excludes Sprint because it has not participated in a spectrum auction since 1997.

The broadband-only analysis is similar, except that in this case Verizon and AT&T do not appear to pay significantly different prices from each other (Figure 9). T-Mobile, Leap, US Cellular, MetroPCS, and everyone else have paid less than AT&T (and Verizon) for licenses that allow broadband.

Figure 9: Differences in Average Prices Paid by Carrier for Broadband Licenses

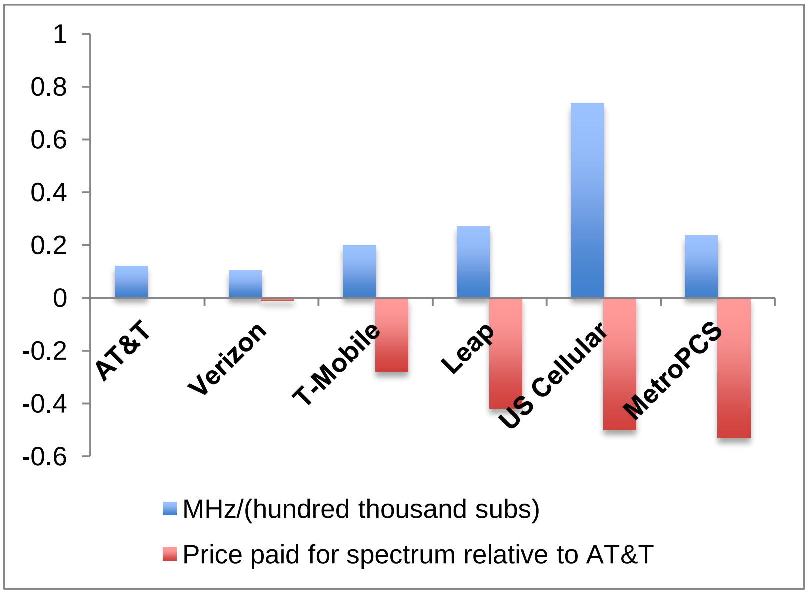


Note: Figure shows how much more or less each carrier paid for licenses relative to other carriers on average, all else equal. AT&T is the baseline because it was the excluded indicator dummy variable. Bar shows coefficient on carrier dummy variable from specification using unique frequency use-tag combinations. Line shows 95 percent confidence interval.

The results suggest that AT&T and Verizon value incremental spectrum more than do other carriers, all else equal. What might explain this difference? Two competing, though not mutually exclusive, hypotheses offer potential answers.

The first hypothesis is that spectrum is valuable to AT&T and Verizon because although they are the leading networks in terms of the number of subscribers, coverage, and (generally) technology they have relatively little spectrum in terms of MHz per subscriber. When normalizing spectrum holdings that way, it is sensible that additional spectrum on the margin is more valuable to them than it is to others. Figure 10 lends support to this hypothesis. Firms with more spectrum per subscriber tend to pay less for spectrum than firms with less spectrum per subscriber.

Figure 10: Average Spectrum Depth per Hundred Thousand Subscribers and Difference in Price Paid



Note: Spectrum depth and subscribers as of Q4 2011. Verizon spectrum holdings do not include spectrum acquired from SpectrumCo.

Sources: Derived from Feldman (2012), Goldstein (2012), and Moffett (2011).[51]

The second hypothesis is that AT&T and Verizon value additional spectrum not just because it is necessary to provide services, but because each MHz of spectrum they control is a MHz of spectrum a competitor does not control. That is, under this foreclosure hypothesis, AT&T and Verizon derive extra value from spectrum because keeping it away from competitors makes it more difficult to compete.[52]

Testing the foreclosure hypothesis is difficult because it is not obvious what the auction price in the absence of foreclosure "should" be. If other potential bidders believe they have no chance of outbidding Verizon or AT&T for spectrum then they would be unlikely to enter the bidding in the first place. Under that scenario we would probably expect the two biggest carriers to spend *less* per MHz-POP than others because there would be fewer bidders in the auction, but we know the opposite is true—they spend more than others.

Another possibility—consistent with higher prices paid by AT&T and Verizon—is that the two carriers offer very high bids to signal to others the futility of continuing to bid in the auction. We would then probably expect auctions won by AT&T or Verizon to conclude in fewer rounds than

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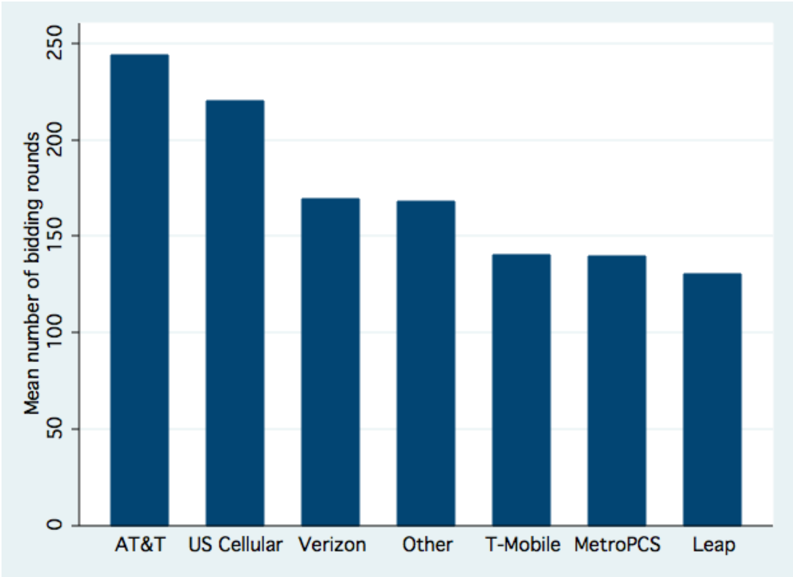
[51] Brett Feldman, *Key Updates on Major Spectrum Deals* Industry Update (Deutsche Bank, Markets Research, February 5, 2012); Phil Goldstein, "MetroPCS, Leap Post Sequential Subscriber Gains in Q4," *FierceWireless*, January 5, 2012, http://www.fiercewireless.com/story/metropcs-leap-post-sequential-subscriber-gains-q4/2012-01-05; Craig Moffett, *AT&T Buys T-Mobile: A "High Degree of Confidence" That the Deal Can Get Done* (Bernstein Research, March 21, 2011).

[52] See, for example, Harold Feld, "Spectrum Efficiency V. Competition Part II: Why Do Verizon and AT&T Keep Ending Up With All The Spectrum?," *Tales of the Sausage Factory*, March 15, 2012, http://tales-of-the-sausage-factory.wetmachine.com/spectrum-efficiency-v-competition-part-ii-why-do-verizon-and-att-keep-ending-up-with-all-the-spectrum/.

other auctions, either due to fewer initial bidders or large opening bids by AT&T or Verizon as a signal regarding their determination to win.[53]

Figure 11, however, shows that the presence of AT&T and Verizon in an auction does not tend to diminish the auction competition in terms of number of rounds to completion. In other words, the claim that participation by the two largest providers dampens auction competition appears to be false.[54]

Figure 11: Mean Number of Rounds in Auctions for Licenses that Allow Broadband by Auction Winner



In sum, at the end of the day we are left with the information that AT&T and Verizon pay more than others, all else equal, for their spectrum, some evidence in favor of the efficiency hypothesis and some evidence against a component of the foreclosure hypothesis. However, there is no way to rule out or in either completely.

Prices and a Spectrum Crunch

If the analysis controlled for all other factors affecting the private value of spectrum licenses, then the remaining year effects should reveal the net effect of demand and technological change on private spectrum value. However, the analysis above cannot accurately identify price because each auction tends to occur within a particular year. As a result, in some cases the year fixed effects capture price changes, but other times they reflect differences between the type of licenses being sold for which the model does not otherwise control. So, for example, the

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[53] The degree to which this type of action is possible depends in part on the auction rules. For example, after the 2008 AWS auction the FCC changed the auction rules to make this kind of signaling more difficult. Additionally, Bulow, Levin, and Milgrom (2009) point out that so-called "jump bidding" may be used for reasons other than signaling, such as to gain some control over the auction. Jeremy Bulow, Jonathan Levin, and Paul Milgrom, "Winning Play in Spectrum Auctions" (Stanford, CA, February 2009), http://www.stanford.edu/~jdlevin/Papers/AWS.pdf.

[54] Another problem with the foreclosure mechanisms discussed above is that the FCC designs its auctions to minimize that type of behavior. For example, the FCC sometimes uses blind bidding so that any given bidder does not know who the other bidders are, although with certain large auctions it may be inherently obvious who the bidders are.

coefficient on the 2011 dummy variable partly captures the price effect, but also captures Auction 92 effect, especially in the broadband-only equation where it is not possible to otherwise control for radio service.

The model therefore must be changed slightly for the purposes of estimating price changes. This section focuses more explicitly on the price index[55] and compares the results to those we can observe in secondary market trades.

The simplest difference from the above analysis is that hedonic price index is typically constructed as a log-linear model rather than a linear model, making it easier to interpret the coefficient on the year dummy variables as percent changes in price.[56] Additionally, estimating a single equation with multiple year dummy variables (the pooled method) as above constrains the other coefficients to remain constant across years, which may not be justified. Instead, the "adjacent period dummy variable approach" allows all coefficients to vary across years by estimating separate equations for each adjacent year pairs.[57]

Most importantly, however, licenses are probably too heterogeneous to make year-to-year comparisons meaningful, as evidenced by the unrealistic magnitude of the estimated price changes from the above regressions. For example, 700 MHz and, say, paging licenses are probably too different to pool together, even when controlling for their radio service code. Even 700 MHz and AWS-1 licenses may be too different to pool. Separate models for paging, 700 MHz, AWS-1, and so on will be more realistic than pooling them and trying to control for their different characteristics.

Taking into account the above comments, I estimate log-linear adjacent-period fixed effects models separately for each radio service. Because not all radio services are represented in each auction, adjacent periods can be several years apart.

The advantage of the radio service-specific, adjacent-year approach is that it yields a much cleaner, apples-to-apples comparison of changes in license values since the approved uses are close to identical.[58] The disadvantages is that the analysis has no common base year on which to construct a single spectrum price index, although I present some estimates of a plausible consolidated index under different assumptions.

I don't present the full regression results here. Instead, I present just the radio service-specific results. Table 6 shows auction years, average price of the licenses auctioned, range of years it

[55] For an excellent discussion of price indices, see Jack E. Triplett, *Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes: Special Application for Information Technology Products* STI Working Paper (OECD, October 8, 2004), http://www.oecd.org/science/sci-tech/33789552.pdf.

[56] Estimating the all-license regression above as a log-linear model suggests a price change of about 150 percent between 2007 and 2011 (approximately 25 percent annual growth rate), which seems plausible but still high, as secondary trades discussed below highlight.

[57] Triplett, *Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes: Special Application for Information Technology Products*, 50–51.

[58] "Radio services," available on the FCC Spectrum Dashboard, are not the same as the full list of radio service codes (http://wireless.fcc.gov/uls/index.htm?job=radio_services). Thus, it is likely that some licenses categorized as a particular "radio service" here may include somewhat different collection of radio service codes. Got that? No? Welcome to the world of spectrum licenses.

was possible to estimate a price index, percentage price increase based on the hedonic regression, the index, and a graphical representation of the index. Close inspection of the table shows why a hedonic model is different from simply looking at price changes. Consider the 700 MHz radio service, for example. Licenses in the much smaller 2011 auction sold for $0.56 per Mhz-POP compared to $1.10 in the 2008 auction. Simply looking at those prices would lead one to conclude that the spectrum sold for half as much in 2011 as in 2008. Controlling for factors that affect license value, like the nature of the geographic areas covered by these licenses, suggests that, instead, the price almost doubled.

The different years for which it is possible to estimate these indices makes it difficult to compare across radio service code. To facilitate this comparison, Figure 12 shows the price indices for the five radio services whose auction revenues totaled at least $500 million.[59] The figure shows that radio service prices do not move together. Among the services pictured, the value of the 700 MHz spectrum increased the most—about 30 percent annually between 2008 and 2011. Licenses designated for wireless cable, a service that did not become popular, showed the biggest price decrease among those pictured.

[59] The $500 million cutoff is arbitrary, but adding more radio services made the figure increasingly complicated while the marginal increase in information arguably decreases as auction revenues decrease.

Table 6: Radio Service Price Indices

Auction year	Years change measured	Average $/MHz-POP	Total Amount Spent in Auctions ($ millions)	Percent Change in Price Index	Annualized Change	Price index
PCS			$22,800			
1996		$1.94	$905			
1997		$0.33	$2,520			
1999	1997 - 1999	$0.16	$413.0	-63%	-39.4%	
2001	1999 - 2001	$4.19	$16,900	1840%	340.5%	
2005	2001 - 2005	$0.98	$2,040	-67%	-24.4%	
2007	2005 - 2007	$0.23	$13.9	-58%	-35.0%	
2008	2007 - 2008	$0.21	$7.9	-27%	-26.7%	
700 MHz			$19,477			
2003		$0.03	$57			
2005		$0.05	$0.3			
2008	2003 - 2008	$1.10	$19,400	977%	60.9%	
2011	2008 - 2011	$0.56	$20	111%	28.2%	
AWS-1			$13,713			
2006		$0.54	$13,700			
2008	2006 - 2008	$0.08	$13	36%	16.5%	
Wireless Cable			$743			
1998		$0.002	$579			
1999	1998 - 1999	$0.001	$45.1	161%	161.1%	
2004	1999 - 2004	$0.002	$119	-87%	-33.7%	
2005		*	$0.1			
700 MHz Guard Band			$541			
2000		$0.35	$520			
2001	2000 - 2001	$0.47	$21.0	85%	84.7%	
Specialized Mobile Radio Service (SMR)			$450			
1997		$0.04	$96			
2000	1997 - 2000	$0.12	$348	50%	14.6%	
2002	2000 - 2002	$0.06	$1.4	-49%	-28.8%	
2004		$0.09	$4.9			
Wireless Communications Services (WCS)			$150			
1997		$0.002	$13.6			
2003		$0.01	$12.6			
2007	1997 - 2007	$0.05	$124	2264%	37.2%	
Lower 700 MHz			$146			
2002		$0.03	$89			
2003	2002 - 2003	$0.03	$57	-9%	-9.1%	
2005		$0.05	$0.3			
Paging			$25			
2000		$0.04	$4.1			
2001	2000 - 2001	$0.03	$12.9	-34%	-33.9%	
2003	2001 - 2003	$0.02	$2.4	-14%	-7.2%	
2010	2003 - 2010	$0.02	$5.4	34%	4.2%	
220 MHz			$24			
1998		$0.07	$21.7			
1999	1998 - 1999	$0.03	$1.9	-24%	-24.2%	
2007	1999 - 2007	$0.01	$0.2	-81%	-18.5%	
Public Coast			$23			
1998		$0.07	$22.0			
2001	1998 - 2001	$0.002	$1.1	-85%	-46.4%	
Multiple Address Systems			$9			
1999		$0.001	$3.4			
2001	1999 - 2001	$0.01	$1.2	1705%	324.8%	
2005	2001 - 2005	$0.04	$3.9	51%	10.8%	
Narrowband PCS			$9			
2001		$0.02	$8.3			
2003	2001 - 2003	$0.01	$0.4	-9%	-4.8%	

Figure 12: Price Indices for Five Radio Services

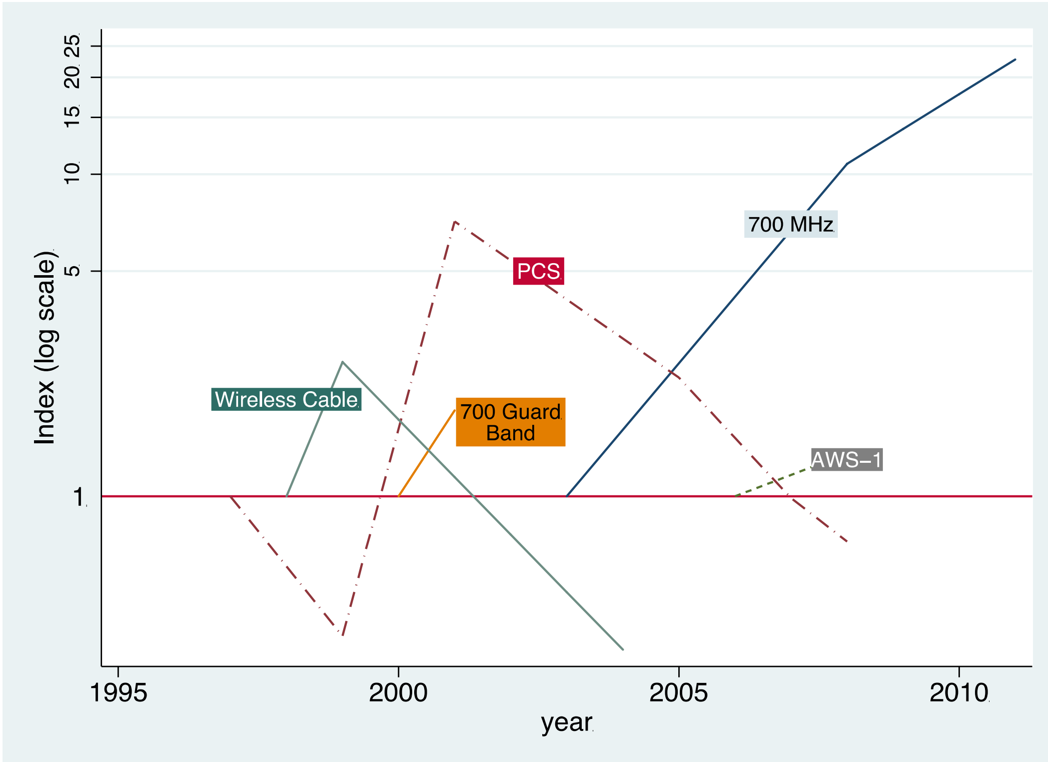
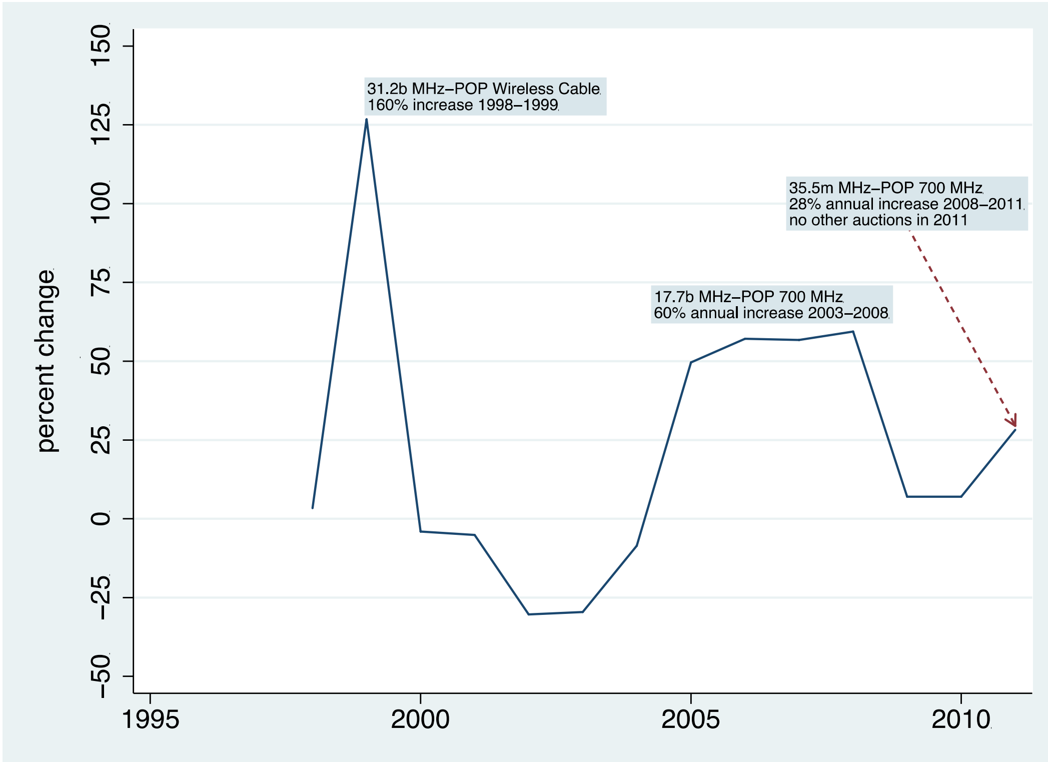


Figure 12 also highlights the inherent difficulties in using auction data to develop price indices. Because auctions are relatively infrequent and auctions of any given spectrum type even more infrequent, any single index would be dominated by different types of spectrum in different years. For example, the most recent auction price data come from the relatively small 2011 auction of 700 MHz spectrum, which the hedonic model estimates reflects about a 28 percent annual increase since the 2008 auction.

Despite these shortcomings, it is possible to combine these estimates into a single index, though the result should be taken as illustrating trends rather than specific price changes. Figure 13 combines the above estimates by weighting the estimated annual changes by the amount of spectrum (in MHz-POPs) involved. This approach leads to certain oddities in the figure, such as a spike in 1999 suggesting a 125 percent price increase, which is an artifact of the one time the price of auctioned wireless cable spectrum increased.

Figure 13: A Consolidated Index Based on Adjacent-Year Hedonic Model



While the number for any given year should be interpreted only after carefully considering its foundation in Table 6, Figure 13 illustrates two general points. First, spectrum prices appeared to dip after 2001 and the dot-com and technology market collapse. Second, beginning sometime around 2005 prices recovered and have increased each year since.

As discussed above, analysis based on secondary trades would yield a more precise price index by comparing changes in the price of individual licenses over time.[60] While the FCC records license ownership information, it does not record the price of the thousands of such trades made each year. The only price data routinely publicly available is for very large transactions. Estimating changes from large transactions, like auction data, is also problematic in certain ways. Most importantly, the trade may not be strictly cash-for-spectrum, but may involve other exchanges or agreements whose value is difficult to quantify.

Despite the problems with large secondary trades, they add important information to the question of changes in spectrum value. The 2013 spectrum trade between AT&T and Verizon shows the value and difficulty in evaluating secondary trades. In this transaction, Verizon sold about 495 million MHz-POPs of 700 MHz spectrum to AT&T in exchange for $1.9 billion and 243 million MHz-POPs of AWS-1 spectrum. Craig Moffett estimates that this trade yielded a 4.1 percent

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[60] Ideally, such an index would be similar to the Case-Shiller Housing Price Indices, which track individual houses as they change hands (S&P Dow Jones, *S&P/Case-Shiller Home Price Indices*, December 30, 2011.). In 2009 SpectrumBridge, which hoped to provide a platform for secondary trades, launched a spectrum index based, presumably, on the trades it facilitated (http://spectrumbridge.com/AboutUs/Overview.aspx). Unfortunately, that index appears to no longer be available.

annual return to Verizon on spectrum it acquired in 2008, far lower than the 28 percent annual return estimated for 2008-2011 in the hedonic model.[61]

Table 7 shows several large secondary trades made since 2002. The table shows high variance in annualized change in license values, ranging from a high of 121 percent for 700 MHz licenses sold in 2007 to a loss of 7 percent for PCS licenses sold in 2010.

Table 7: Selected Major Secondary Spectrum Transactions

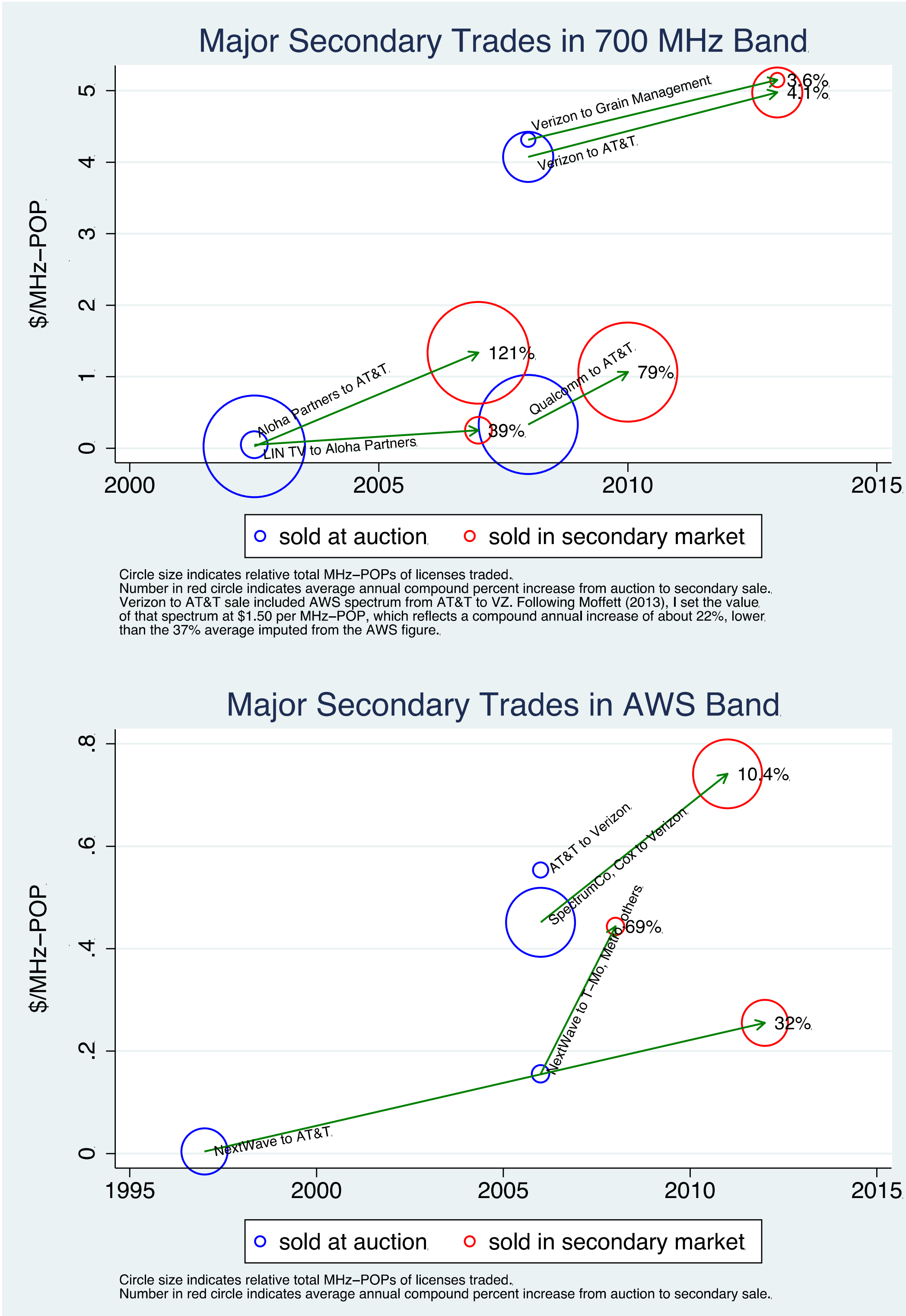
Buyer	Seller	Year Auctioned	Year Resold	Band Type	$MHz-POP		Annualized percent increase
					At auction	At resale	
Verizon	NorthCoast	1997	2002	PCS	$0.26	$1.69	45%
Verizon	Qwest	1997	2004	PCS	$0.50	$1.26	14%
Verizon	NextWave	1996, 1997	2004	PCS	$1.59	$1.90	2.3%
Aloha Partners	LIN TV	2002, 2003	2007	700 MHz	$0.05	$0.25	39%
AT&T	Aloha Partners	2002, 2003	2007	700 MHz	$0.03	$1.34	121%
T-Mobile, Metro PCS, others	NextWave	2006	2008	AWS-1	$0.16	$0.44	69%
AT&T	Qualcomm	2003, 2008	2010	700 MHz	$0.33	$1.07	79%
Sprint	Wirefree	2005	2010	PCS	$0.83	$0.58	-6.9%
Verizon	SpectrumCo, Cox	2006	2011	AWS-1	$0.45	$0.74	10.4%
Sprint	US Cellular	1995	2012	PCS	$1.00	$0.96	-0.3%
AT&T	NextWave	1997, 2006	2012	AWS-1, WCS	$0.00	$0.26	32%
AT&T	Verizon	2008	2013	700 MHz	$4.07	$4.98	4.1%
Grain Management	Verizon	2008	2013	700 MHz	$4.31	$5.15	3.6%

Sources: Company press releases, FCC Universal Licensing System Database, FCC auction data, and Moffett (2013).[62]

Figure 14 shows this information graphically for AWS and 700 MHz spectrum license trades. The most recent transactions are the 4 percent annualized return from Verizon's sale to AT&T in 2013 discussed above and a 3.6 percent return from Verizon's sale to Grain Management the same year. However, the sale of NextWave's AWS-1 and WCS spectrum to AT&T a year earlier resulted in a 32 percent annual return and SpectrumCo's sale to Verizon netted a 10.4 percent annual return.

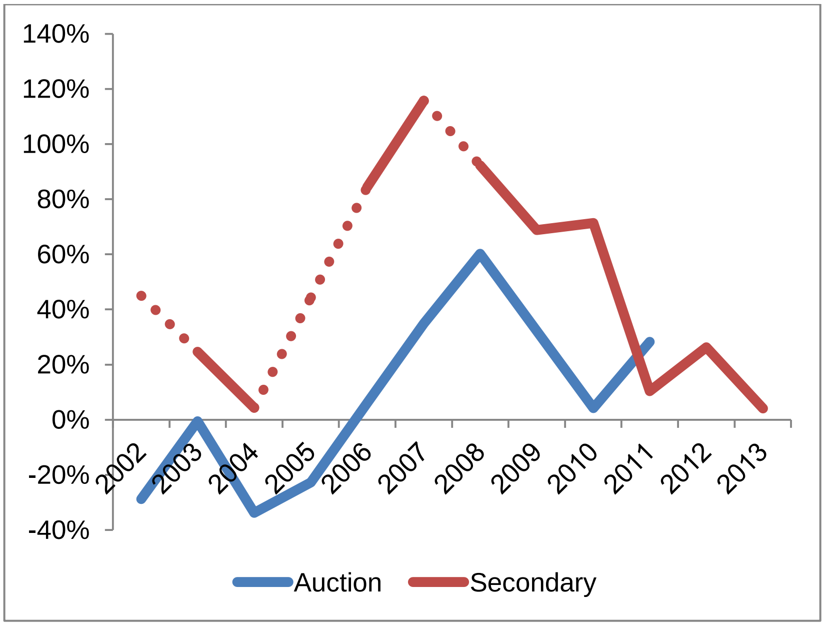
[61] Craig Moffett, *Quick Take - Searching for Meaning in AT&T's and Verizon's Spectrum Deal... Three Lessons* (AllianceBernstein, January 28, 2013).
[62] Ibid.

Figure 14: Major Trades of 700 MHz and AWS Spectrum Licenses



The various methodological approaches and data used in this paper provide plausible bounds on the true change in spectrum prices. Between 2010 and early 2013 estimates of annualized changes range from about 4 percent to around 30 percent. We can, therefore, safely conclude that spectrum prices have been increasing, but not precisely by how much.[63] As a final exercise, it is worth consolidating the results to the extent possible. Figure 15 shows annualized returns, weighted by MHz-POPs for the year of auction or resale. It is encouraging to note that the auction and resale methods show similar trends. If these estimates are to be believed, spectrum prices began increasing in the mid-2000s, with the rate of increase peaking in 2007 or 2008, and returning to single digit increases by late 2012-early 2013.

Figure 15: Summary of Price Changes Derived From Auctions and Secondary Trades



These results come with caveats. First, as the large estimated range suggests, each type of analysis has its own strengths and weaknesses as discussed *ad nauseum* above. Second, each carrier faces a unique situation. Some carriers may, for example, have a pressing need for additional AWS spectrum and little need for 700 MHz spectrum, or vice-versa.

Second, the hedonic analysis here is a reduced-form model and largely assumes the auction and usage rules are exogenous. That is, it assumes that the FCC sets the rules and then bidders decide how much licenses are worth to them as if the bidders were simply economic actors in a typical market. The reality is not so simple.

The reality is that the FCC does not set auction rules, bandplans, or use rules in a vacuum. Instead, as it prepares for an auction it issues a Notice of Inquiry, Notice of Proposed Rulemaking and possibly Further Notices of Proposed Rulemaking, and finally an Order describing the final rules. Every actor with a (real or perceived) interest in the auction submits comments and meets with regulatory officials when possible. The Commission then does its best

[63] As Carveth Read wrote in 1898, " is better to be vaguely right than exactly wrong." http://www.gutenberg.org/files/18440/18440-h/18440-h.htm#Page_351.

to set rules that it believes will be facilitate an efficient market-like outcome. In other words, the license rules are partly endogenous to the price paid. That said, it is not immediately obvious how this particular endogeneity affects the results.

Conclusion

This paper disentangles and quantifies the factors affecting private spectrum value, and measures changes in prices over time. I find that flexible-use licenses are significantly more valuable than licenses that dictate specific allowed uses and that policy uncertainty depresses license value. I also find evidence that, all else equal, license prices increased steadily since about 2007, suggesting that demand for wireless services has been outpacing improvements in technological efficiency. However, the range of estimated change is large—between 4 and 30 percent annually for 2011 and 2012 and the rate of price increase has probably been slowing. Whether or not spectrum values justify the moniker "crisis," the results emphasize the economic costs of artificially restricting the supply or use of spectrum, the complex interplay of factors that affect spectrum license value, and the importance of making long-term credible regulatory commitments.

Appendix: Radio Services

Radio Service Name	Description [FCC source in footnote]	All licenses auctioned	Number licenses sold in auctions since 1996
Commercial Air-Ground Radiotelephone Service	Allows licensees to provide two-way voice, fax and data services to subscribers in aircraft, in-flight or on the ground.	2	2
AM Broadcast	Dissemination of radio communications intended to be received by the public and operated on a channel in the AM broadcast band.	3	3
Advanced Wireless Service (AWS-1)	Licensees may provide any type of terrestrial mobile or fixed service (but not broadcasting).	1157	1122
Broadband Radio Service	Accommodates a variety of applications, including terrestrial fixed and mobile and one-way and two-way broadband services.	78	61
FM Broadcast	A station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radio telephone emissions intended to be received by the general public.	687	639
Interactive Video and Data Services (IVDS)	A point-to-multipoint, multipoint-to-point, short distance communication service. An IVDS licensee may transmit information, product and service offerings to its subscribers and receive interactive responses. Mobile operation is permitted.	594	0
Multiple Address Service	Used for fixed terrestrial point-to-multipoint, fixed point-to-point, and mobile communications. Content may include licensee`s products or services, excluding video entertainment material, to a licensee's customer or a licensee`s own internal communications. Site-based MAS licensees typically use the spectrum for point-to-multipoint internal communications such as Supervisory Control And Data Acquisition, alarm monitoring, and mobile meter reading systems.	9858	3390
Narrowband Personal Communication Service	Narrowband mobile operation, such as two-way paging and other applications.	465	377
Paging and Radiotelephone Service	Traditional commercial paging service consists of one-way data communications (callback number, short message, information update, etc.) sent to a mobile device.	37818	23933
Broadband Personal Communication Service	Any type of terrestrial mobile or fixed service. Usage is mostly two-way mobile voice and data services direct to consumers.	3158	2975
VHF Public Coast	Fixed, mobile, or hybrid voice or data communications. Service may be provided to land if marine communications have priority.	305	249
Digital Audio Radio Service	Nationwide radio programming with compact disc quality sound via satellite. DARS has the potential to offer high quality radio signals to listeners who currently receive few terrestrial signals.	2	2
Direct Broadcast Satellite	Satellite transmission of voice, video, and data direct to the consumer. DBS is a direct-to-home satellite service that permits delivery of digitally-compressed audio and video signals to individual households by means of an 18 inch dish receiving antenna.	5	5

Upper 700 MHz Guard Bands	By Congressional direction, the Commission reallocated thirty-six megahertz of spectrum for commercial use including fixed, mobile, and broadcasting services. Six of the thirty- six megahertz were Guard Bands to protect public safety users. Guard band equipment must meet ACCP OOBE criteria and users must comply with frequency coordination procedures. Entities that employ a cellular system architecture are prohibited from operating in this band.	112	104
700 MHz	Licensees may provide any type of terrestrial mobile or fixed service. One 2x11 MHz block ("C Block") includes requirement to provide open access for devices and applications. Consideration of one 2x5 MHz pair ("D Block") as a resource to facilitate a Public Safety Broadband Network along with adjacent Public Safety spectrum.	2115	1846
Specialized Mobile Radio Service	Any terrestrial mobile or fixed service. Usage is mostly 2-way mobile voice and data services. Includes site-specific business/ industrial/ land transportation, public safety and commercial licensees and overlay geographic auction based commercial licensees.	5476	5452
Wireless Communication Service	Any fixed, mobile, radiolocation or broadcast-satellite (sound) use consistent with international spectrum allocation agreements.	193	191
Multipoint / Multichannel Distribution Services	"Wireless Cable" permits delivery of video programming through microwave antennas. Channels allocated to MDS generally provide a multichannel video programming service similar to cable television, but use microwave frequencies instead of cables.	1876	1732
Super-High Frequency 39 GHz or 24 GHz	39 GHz licensees may provide fixed communications including point-to-point and point-to-multipoint communications. Mobile communications are subject to the development of inter-licensee and inter-service interference criteria. The 24 GHz Radio Service can be used for any kind of digital fixed communications service consistent with Commission rules. Services can be provided on a common carrier or non-common carrier basis.	3330	2180
Automated Maritime Telecommunications Service	A specialized system of coast stations providing integrated and interconnected marine voice and data communications, somewhat like a cellular phone system, for tugs, barges, and other vessels on waterways. Service to units on land is permitted, so long as marine-originating communications receive priority.	30	20
TOTAL		**68,668**	**45,425**