The Potential Market Value and Consumer Surplus Value of

The Citizens Broadband Radio Service (CBRS) at 3550-3700 MHz in the United States

Harold Furchtgott-Roth*

November 2017

ABSTRACT: The Citizens Broadband Radio Service (CBRS) spans 3550 – 3700 MHz. It represents approximately a 16% expansion of licensed spectrum below 4 Ghz. Wireless services based on available wireless spectrum have been a substantial source of technological innovation and economic growth over the past few decades. Based on reasonable assumptions, the estimated market value of CBRS ranges from $7.5 to $15.6 billion. The estimated annual consumer surplus of CBRS ranges from $8 billion to $26 billion. The estimated net present value of consumer surplus ranges from $80 billion to $260 billion.

* President, Furchtgott-Roth Economic Enterprises. This research has been partially underwritten by the CBRS Alliance. Any errors in the report are entirely those of the author.

I. BACKGROUND AND INTRODUCTION

This paper examines the economic value of a large band of spectrum, the Citizens Broadband Radio Service (CBRS) at 3550-3700 MHz newly available for commercial application on a licensed basis. Before examining this band in detail, it is important to understand the context of why spectrum is important to wireless technology, and why wireless technology is important to the American economy.

A generation ago, wireless services were the identifiable exception rather than the rule in the American economy. Yes, Americans received information and entertainment through one-way broadcasting, but wireless services did not permeate every element of economic activity or influence and reinforce every aspect of our daily lives. No more. Over the past 40 years, wireless services have transformed the American economy. A generation ago, broadcasting and a few other wireless services accounted for an identifiable, small sector of the economy. Today, wireless services are used by every sector of the economy. More than a half trillion dollars of wholesale trade is for "Commercial and Professional Equipment and Supplies,"[1] most of which has some embedded form of wireless technology. Hundreds of billions of dollars are added through wireless and related services. Remove wireless services, and practically every sector of the American economy would come to a virtual stop. Various studies show the substantial contribution

[1] U.S. Census Bureau, "Sales, U.S. Merchant Wholesalers, 2015," (the most recent year available," at https://www.census.gov/wholesale/index.html.

of the wireless industry to the American economy[2] and the importance of property rights for spectrum to that economic growth.[3]

It is not merely that wireless technology and services have enhanced economic activity, they have also changed how we live our daily lives. A generation ago, we had no choice but to travel to a store to make purchases, to travel to a bank to have financial services, to travel to a place of work to be employed, to travel to hospital or doctor's office to receive medical services. Today, we can do practically any activity remotely, thanks in large part to new wireless technologies. Tomorrow, computerized machines, relying heavily on wireless technologies, may be able to drive us across country, perform delicate surgical operations, and organize entire warehouses of supplies.

These wireless services simply did not exist a generation ago. Technological innovations, much created in the United States, have changed our economy, both measurably and immeasurably. These wireless innovations have created wealth for innovators and investors and value for consumers. Although we can measure changes in wealth and income, and although we can measure how much consumers pay for new wireless technologies and services, we cannot fully measure the entire value of these new innovations. We cannot measure the joy of a grandparent seeing through a mobile

[2] See, e.g., H. Furchtgott-Roth, *The Wireless Sector: A Key to Economic Growth in America*, report prepared for CTIA, January 2009.
[3] H. Furchtgott-Roth, "The Economic Value of Property Rights Concepts in Spectrum, Both With and Without Licenses," Hudson Institute Center for the Economics of the Internet, April 4, 2017, at https://hudson.org/research/13502-the-economic-value-of-property-rights-concepts-in-spectrum-both-with-and-without-licenses.

application a grandchild half way around the world or the value of a life saved or improved by new medical technologies dependent on wireless technologies.

While American businesses and innovators have been at the forefront of creating new wireless technologies, the consumer benefits have been shared by practically everyone around the world. New wireless services have been among the most rapidly diffused technologies in history. A generation ago, there were no wireless phones or WiFi hotspots or other forms of wireless technologies. Today, it is hard to find a hidden corner of the world without these technologies and without consumers enjoying them.

Spectrum is the fuel that energizes wireless services and wireless innovation. More spectrum available for commercial and personal wireless services means more wireless services and consumer value.[4] Signals in spectrum below 3 GHz have particularly attractive physical properties of traveling long distances and penetrating buildings. Yet much spectrum below 3 GHz is reserved for government uses, and specific applications that limit and even prohibit technological innovation. The Federal Communications Commission in reviewing mergers considers less than 600 MHz of the spectrum below 3 GHz—that is, less than 20% of available spectrum—as worthy of consideration.[5] Although spectrum in bands above 3 GHz has been important to innovation and to the development of wireless services, much attention has focused on less than 600 MHz

[4] CTIA has a "Quick Fact" stating that each additional 10 MHz of spectrum leads to $3 billion in GDP. https://www.ctia.org/industry-data/wireless-quick-facts, accessed August 30, 3017. I believe that CTIA has hopelessly understated the true value of spectrum and its contribution to American economy for consumer value and technological innovation.
[5] FCC, Wireless Competition Report, 19th Annual Report, September 23, 2016, Table IV.A.1.

below 3 GHz. Advances in technology have made spectrum in higher bands of increasing commercial value. Those include the 3.5-3.6 GHz band.

In 2015, the Federal Communications Commission opened up an additional 150 MHz of spectrum in the 3.5-3.6 GHz band, one of the last major spectrum frontiers below 4 GHz.[6] The FCC modified rules affecting the band in 2016.[7] Even conservatively excluding as much as 50 MHz for incumbent users, this band represents approximately a 16% expansion of licensed spectrum ((150 MHz-50 MHZ)/600 MHz) below 4 GHz of intense commercial interest. China, Japan, Korea, Europe and other countries have allocated part or all of the band for mobile broadband.[8] The Europeans claim this band is how Europe will move ahead in wireless 5G technologies.[9] Other countries are developing the band as well.

So too is the United States, but clearing spectrum has been difficult. Important incumbent users, particularly federal defense users, occupy part of the band complicating

---

[6] FCC, Report and Order and Second Further Notice of Proposed Rulemaking, ("Report and Order") Amendment of Commission's Rules with regard to commercial operations in 3550 – 3650 MHz, April 21, 2015.

[7] FCC, Order on Reconsideration and Second Report and Order ("Order on Reconsideration"), Amendment of Commission's Rules with regard to commercial operations in 3550 – 3650 MHz, May 2, 2016.

[8] See, e.g., Dimitris Mavrakis, "Analyst Angle: Is C-Band the next frontier for 5G spectrum?" RCR Wireless News, July 26, 2017, at https://www.rcrwireless.com/20170726/opinion/20170726wirelessanalyst-angle-is-c-band-the-next-frontier-for-5g-spectrum-tag9, accessed August 28, 2017.

[9] "The RSPG considers the 3400-3800 MHz band to be the primary band suitable for the introduction of 5G -based services in Europe even before 2020, noting that this band is already harmonised for mobile networks, and consists of up to 400 MHz of continuous spectrum enabling wide channel bandwidth. This band has the possibility to put Europe at the forefront of the 5G deployment." "Strategic Roadmap Towards 5G for Europe," European Commission, Radio Spectrum Policy Group, November 9, 2016, Section 2.1

a more familiar approach of stand-alone licensed spectrum band. Instead, in 2015, the Federal Communications Commission (FCC) adopted a new and novel approach to spectrum with tiers of users sharing all of the 150 MHz of spectrum. The FCC introduced its report and order with the following paragraph:

> With this Report and Order (Report and Order or R&O), we adopt rules for commercial use of 150 megahertz in the 3550-3700 MHz band (3.5 GHz Band), and in so doing open a new chapter in the history of the administration of one of our nation's most precious resources—the electromagnetic radio spectrum. Wireless broadband is transforming every facet of American life. We live in a world of wirelessly connected people, apps, and things. The 3.5 GHz Band has physical characteristics that make it particularly well-suited for mobile broadband employing small cell technology. The creation of our new Citizens Broadband Radio Service in this band will therefore add much-needed capacity to meet the ever-increasing demands of wireless innovation. As such, it represents a major contribution toward our collective goal of making 500 megahertz newly available for broadband use.[10]

The promulgated rules for of the new Citizens Broadband Radio Service (CBRS) at 3550 – 3700 MHz are in Parts 0, 1, 2, 90, 95, and particularly the new Part 96 of the Code of Federal Regulations.[11] Commercial use of the band will soon be here. Both Qualcomm[12] and Intel[13] have announced chipsets that will include the CBRS band. Before long, these chipsets will be in consumer handsets.

---

[10] FCC, Report and Order, paragraph 1. [footnotes omitted]
[11] Ibid., Appendix A.
[12] See, e.g., "Qualcomm Extends Connectivity Leadership with Second Generation Gigabit LTE Modem," February 21, 2017, Qualcomm blog at https://www.qualcomm.com/news/releases/2017/02/21/qualcomm-extends-connectivity-leadership-second-generation-gigabit-lte, accessed August 29, 2017, and "Taking 3.5 GHz CBRS from spec to product with chipset solutions spanning small cells to mobile," August 16, 2017, Qualcom blog, at https://www.qualcomm.com/news/onq/2017/08/16/taking-35-ghz-cbrs-spec-product-chipset-solutions-spanning-small-cells-mobile, accessed August 29, 2017.
[13] "CBRS: Your ticket for building a private enterprise LTE wireless network," *NetworkWorld*, March 14, 2017, at https://www.networkworld.com/article/3179784/mobile-wireless/the-big-cbrs-promise-private-enterprise-lte-wireless-networks.html, accessed August 29, 2017.

This paper examines the potential market value and consumer value of the CBRS band. It is difficult to overstate the importance of freeing up 1 MHz of more spectrum for commercial application, let alone the 150 MHz of CBRS spectrum. In part, spectrum is a completely non-depletable resource; using 150 MHz of CBRS spectrum today does not lessen the amount of CBRS spectrum available tomorrow. Under this circumstance, it is economically efficient to bring more spectrum into use.

Different bands of spectrum are differentiated in their physical properties and in their range of commercial applications. The CBRS band will be no different. There is reason to believe that new technologies and new applications will emerge in the CBRS band, just as they have emerged in other bands. Although there is not necessarily a one-to-one correspondence between available spectrum on the one hand and innovation and economic growth on the other, expanding commercial licensed spectrum by 16% will almost certainly have a substantial positive effect on both innovation and economic growth in the United States. Although much of this paper focuses on the direct economic value of the CBRS spectrum band and different licensing structures within it, the contribution to innovation and economic growth spans the entire band.

Before quantifying the value of CBRS spectrum, I first describe the structure and users of the spectrum band in Section II. In Section III, I caution about some of the many difficulties of measuring the value of this spectrum. In Section IV, I describe methods to quantify the value of the spectrum for incumbent users. In Section V, I review possible

values for new priority access license users. Section VI reviews the value for general authorized access.

II. WHAT IS CBRS SPECTRUM?

The structure of the CBRS band is different from the structure of any other band of spectrum in the United States. CBRS is formally shared among federal and non-federal users, and the 2015 Report and Order established three categories of users for CBRS. Using new technologies, a Spectrum Access System (SAS) coordinator coordinates spectrum usage in each census tract.[14]

The FCC has defined three categories of Citizens Band Radio Service Devices (CBSDs) as shown Rule 96.41:[15]

- End user devices:
- Category A – primarily indoor
- Category B – with higher power levels, and outdoor.

Three types of CBRS users are:

Incumbent users

Incumbent users in the CBRS band are largely protected from interference. These are primarily federal users and Department of Defense (DoD) applications,[16] fixed-satellite

[14] 2015 Report and Order, paragraph 4.
[15] 47 CFR, 96.41.
[16] See e.g., 2015 Report and Order, paragraphs 247-275, and 2016 Order on Reconsideration and Report and Order, paragraphs 3 and 8.

services (FSS),[17] and Wireless Internet Service Providers (WISPs),[18] although many WISPs may be transitioned to priority access licenses or general authorized access.

Priority Access License

A Priority Access License (PAL) is an unpaired 10 MHz license in a census tract.[19] The license extends for three years without presumption of renewal.[20] As many as seven PALs will be assigned in each census tract, and one licensee may hold as many as four licenses in one census tract.[21] PALs will be awarded by auction in each census tract where there are multiple applications.[22] PALs may use either Category A or Category B devices. PALs have many potential applications including: (1) mobile operator capacity augmentation; (2) cable and mobile virtual network operator (MVNO) system augmentation; (3) neutral host network for public space; and (4) enterprise LTE.[23]

General Authorized Access

Although all of CBRS including General Authorized Access (GAA) is a licensed service,[24] GAA must accept interference from other CBRS users.[25] As such, the range of services that can be offered under GAA may be more limited, or more easily interrupted, than for PAL. Although GAA can either Category A or Category B devices, Mobile

---

[17] See e.g., 2015 Report and Order, paragraphs 276-296, and 2016 Order and Reconsideration and Second Report and Order, paragraph 25.
[18] See e.g., 2015 Report and Order, paragraphs 387-412, and 2016 Order on Reconsideration and Report and Order, paragraph 36.
[19] 2015 Report and Order, paragraphs 90-101.
[20] Ibid., paragraphs 102-113.
[21] Ibid., paragraphs 114-121.
[22] 2015 Report and Order, paragraphs 90-101.
[23] See, e.g., Mobile Experts, CBRS White Paper, "CBRS: New Shared Spectrum Enables Flexible Indoor and Outdoor Mobile Solutions and New Business Models," (CBRS White Paper), March 2017.
[24] Ibid., paragraph 163.
[25] Ibid., paragraph 162.

Experts expects to see more Category A devices initially under GAA.[26] In some respects, GAA resembles unlicensed use. At least 80 MHz of CBRS spectrum in each census tract will be reserved as GAA. Any entity can use GAA without payment, but only with registration and coordination with the SAS. GAA has some characteristics of an unlicensed service in that anyone can use it, and the service must accept interference. On the other hand, the registration provisions are more akin to a licensed service.

Throughout the report, I compare the value of CBRS spectrum to a measure of the value of 2.5 GHz spectrum largely controlled by Sprint. I do this for at least four reasons: (1) the physical properties of 2.5 GHz spectrum are reasonably close to those of CBRS spectrum; (2) both bands of spectrum can be aggregated into large blocks; (3) both bands of spectrum are today underutilized; and (4) there are publicly available estimates of the market value of 2.5 GHz spectrum. Of course, there are important differences, particularly that the 2.5 GHz spectrum is exclusively licensed to individual licensees and largely controlled by one entity, Sprint. The licensing structure for CBRS will be different, and many different entities may use CBRS spectrum without permission of others.

Nonetheless, to estimate the market value and consumer surplus value of CBRS spectrum, it is helpful to begin with a benchmark of market value, which the 2.5 GHz band provides. Of course, unlicensed applications such as WiFi, Bluetooth, and others

[26] CBRS White Paper, p. 3.

have enormous consumer surplus even though the market value of the unlicensed portion of spectrum used is effectively zero as those rights cannot be bought or sold.

Below, I examine the economic value of CBRS spectrum. I consider the economic value to incumbent users, then PAL users, and finally GAA users. I estimate both the market value of each use as well as the consumer surplus of each use. Thus, by my estimation techniques, incumbent use and PAL users have both substantial market value and consumer surplus value while the GAA users have substantial consumer surplus value. I have no clear basis to provide an economic value to the diffusion of technology and the portfolio of different uses and different users inherent in the widespread availability of both PAL and GAA, unlike 2.5 GHz spectrum. Much as with unlicensed applications, the value of this diffusion and portfolio of uses and users is no doubt large, and I simply have means to estimate it. In that regard, one may consider the estimates of economic values in this report as incomplete and likely underestimating important values.

The value of CBRS spectrum depends substantially on the specific FCC rules, and I discuss some of the factors affecting that value in Appendix A. While those rules are always subject to change, in this paper I assume the rules remain as they are in 2017.

I have seen no conclusive information about the amount of the CBRS band that is reserved for incumbent users. Absent better information, I will conservatively assume one third of CBRS nationwide, or 50 Mhz will be reserved for incumbent users. The allocation of the remaining CBRS band between PAL and GAA depends on demand for

PAL licenses and the reservation of a minimum of 80 MHz for GAA. For purposes of this paper, I will assume the remaining CBRS band is divided as 20 MHz for PAL and 80 MHz for GAA. Other assumptions could be made, but the results of this paper are reasonably robust to those assumptions.[27]

III. VALUING CBRS SPECTRUM FOR INCUMBENT USERS

Market price is a common measure of the economic value of an asset. A useful economic measurement of the consumer value of an asset is *consumer surplus*, the amount above the market price that a consumer would have been willing to pay for a good or service.[28] Thus, we might pay little or nothing for a gallon of water, but, if necessary, we would pay much more for it. For a good such as water or air, the market price is a poor indicator of how much consumers value it. The same is often true of spectrum.

Incumbent users, largely federal agencies, are consumers of CBRS spectrum. The incumbent users never purchased their spectrum rights, and no secondary market for those spectrum rights is readily available. One cannot simply purchase spectrum directly from a federal user. Thus, as measured by market price or even book value, the value of CBRS spectrum for incumbent users would be little or nothing.

In Appendix A, I examine various alternative methods to value spectrum for incumbent users based on the consumer surplus—from the incumbent users' perspective. Table 1

[27] I will also consider in footnotes a scenario with 20 MHz for incumbent users; 50 MHz for PAL; and 80 MHz for GAA.
[28] It is the area under the demand curve but above the market-clearing price.

summarizes the results for incumbent users in the CBRS band. It shows the estimated net present value of consumer surplus with a 10% discount rate of incumbent CBRS licensees nationwide. Depending on the value of spectrum in a different band, and depending on how much spectrum is held by incumbent users, the consumer surplus for those users is measured as ranging between $7 billion and $130 billion depending on the amount of spectrum reserved for incumbent users. If 50 MHz of spectrum were reserved for incumbent users, the relevant information is in the last line of Table 1, with the net present value of consumer surplus ranging from $73 billion to $130 billion.[29] This is implicitly a measure of the value to incumbent users of not being forced to relocate their spectrum operations. Substantial portions of the United States will continue to have incumbent users in the CBRS band, and those users value the CBRS spectrum.

V. VALUING CBRS SPECTRUM FOR PRIORITY ACCESS LICENSE

In each census tract, as many as seven PALs will be awarded auction. These PAL licensees may be wireless carriers, cable operators, telephone companies, private enterprises, or almost any other entity. The PAL licensee and its customers are the consumers of the PAL CBRS spectrum. The PAL licensee will purchase the spectrum rights at auction, and a secondary market for those spectrum rights may become available. At least four methods can be used to value PALs: (1) PAL auctions; (2) value of comparable bands of spectrum (2.5-2.6 GHz); (3) the value of specific applications; and (4) the value of corresponding GAA uses. I review each method in turn.

[29] If only 20 MHz of spectrum were reserved for incumbent users, the net present value of incumbent spectrum would range between $29 billion and $52 billion.

1. The consumer surplus value of PAL as measured through PAL auctions

The first approach is the straightforward value of the PAL auction. Thus if the auction obtains $x for a PAL in a census tract with a population of P[30] corresponds to a commercial auction value of $x/(P x10 MHz).

Of course, as there are more than 74,000 census tracts, and each tract may have as many as seven PALs resulting in as many as 500,000 PAL auction values. The number of estimates of consumer surplus nationwide is quite large. Moreover, the FCC has not announced a schedule for PAL auctions.

2. The consumer surplus value of PAL as measured through the value of comparable bands of spectrum (2.5-2.6 GHz)

Consumer surplus for PAL can also be measured based on the consumer surplus for comparable spectrum with known commercial value. I describe these calculations in Appendix B. In Table 2, I present, with a 10% discount rate, the estimated net present value of consumer surplus for two nationwide 10 MHz PAL. The estimated net present value of consumer surplus ranges from $1.5 billion to $26 billion.[31] The net present value of consumer surplus for PAL is easily in the billions of dollars.

[30] The United States has a population of 325.4 million. Census Bureau Population Clock, https://www.census.gov/popclock/, accessed July 6, 2017. There are 74,134 census tracts in the United States and related areas, https://www.census.gov/geo/maps-data/data/tallies/tractblock.html. Thus the average census tract has a population of approximately 4,390.

[31] If there were five instead of two PAL licenses, the net present value of consumer surplus would range from $3.7 to $65 billion.

3. The value of specific applications

Many of the potential CBRS applications, particularly for PALs, have substantial commercial value including: (1) mobile operator capacity augmentation; (2) cable and MVNO system augmentation; (3) neutral host network for public space; (4) wireless internet service providers (WISPs) particularly in rural areas; and (5) enterprise LTE. Major mobile network operators have been experimenting with special temporary authority (STA) and experimental licenses in the CBRS band, presumably to test capacity augmentation.[32] Charter and other cable operators have interest in CBRS, again presumably for MVNO system augmentation.[33] Potential CBRS applications for neutral host networks and enterprise LTE have substantial potential value.[34] Although details of

[32] See, e.g., "T-Mobile requests 3.5GHz permission from FCC; Charter eyes 28GHz 5G tests," TeleGeography, April 6, 2017, at https://www.telegeography.com/products/commsupdate/articles/2017/04/06/t-mobile-requests-3-5ghz-permission-from-fcc-charter-eyes-28ghz-5g-tests/ M. Alleven, "AT&T files to conduct 3.5-3.7 GHz tests in California's Central Valley," Fierce Wireless, January 24, 2017, at http://www.fiercewireless.com/tech/at-t-files-to-conduct-3-5-3-7-ghz-tests-california-s-central-valley. M. Alleven, "U.S. Cellular files for STA to conduct 3.5 GHz tests," Fierce Wireless, May 29, 2017, at http://www.fiercewireless.com/wireless/u-s-cellular-files-for-sta-to-conduct-3-5-ghz-tests S. Kinney, "Verizon wants to test CBRS small cells," RCR Wireless News, August 17, 2017, at http://www.smallcellhub.com/articles/share/825589/.

[33] See, e.g., B. Munson, "Ruckus: 3.5 GHz LTE will give cable leverage in wireless roaming deals," FierceCable, September 28, 2016, at http://www.fiercecable.com/cable/ruckus-3-5-ghz-lte-will-give-cable-leverage-wireless-roaming-deals S. Kinney, "FCC Gives Charter approval to test 5G in Florida," RCR Wireless News, May 12, 2017, https://www.rcrwireless.com/20170512/5g/fcc-charter-5g-testing-tag17

[34] For example, Mobile Experts estimates that, excluding WiFi investment, enterprise-owned mobile infrastructure expenditures will exceed $1 billion in 2018 and increasing by more than 10% annually. See Mobile Experts, *2017 Enterprise Mobile Infrastructure* report. This figure includes enterprise-driven investments on mobile infrastructure equipment including Distributed Antenna Systems (DAS), Small Cells, and Booster/Repeaters. This forecast represents a global figure, excluding enterprise Wi-Fi investments.

individual business plans are proprietary, the widespread industry interest in the band suggests substantial value.

The CBRS band is potentially of great value for the deployment of wireless broadband services in rural areas. The Wireless Internet Services Providers Association has been an active participant in the FCC's CBRS proceedings supporting both PALs and particularly GAA for rural broadband applications.[35]

4. The value of corresponding GAA services

The FCC determined that incumbent PAL users have absolute priority relative to GAA users as the latter must accept interference from the former.[36] One interpretation is that FCC values the net present value of the consumer surplus of incumbent users and PAL users as greater than that for PAL users. Below we discuss the calculation of consumer surplus for GAA users.

VI. VALUING CBRS SPECTRUM FOR GENERAL AUTHORIZED ACCESS USERS

In each census tract, 80 MHz of CBRS spectrum, eight 10 MHz blocks, are reserved for GAA. GAA users do not pay for the spectrum use, but must register with spectrum coordinators and must accept interference from PAL licensees. In census tracts where there are not a sufficient number of PAL auction bidders, all licenses will be GAA. Many parties, including rural WISPs, have expressed great interest in GAA.

[35] See, e.g., FCC, Comments of the Wireless Internet Service Providers Association, July 24, 2017; reply comments August 8, 2017.
[36] 2015 Report and Order, paragraph 162.

GAA is a hybrid combining the features of unlicensed spectrum in that they are free of charge with licensed spectrum in that GAA users are limited in number in a census tract and must be registered. A few economists have attempted to measure the economic value of unlicensed spectrum.[37] Over the past two decades, unlicensed applications have substantially outpaced licensed applications, yet the value of unlicensed spectrum, while certainly large, is unknown.

In Appendix C, I review some economic considerations in examining the economic value of GAA. I also estimate the net present value of 80 MHz of GAA spectrum. In Table 3, I present, with a 10% discount rate, the estimated net present value of consumer surplus for nationwide 80 MHz of GAA. The estimated net present value of consumer surplus ranges from $5.9 billion to $104 billion. The net present value is easily in the tens of billions of dollars.

VII. THE COMBINED VALUE OF DIFFERENT CBRS APPLICATIONS

The 150 MHz of CBRS spectrum can be allocated in many ways among incumbent users, PAL, and GAA. I will assume that the allocation nationwide is the equivalent on average of 50 MHz for incumbent use, 20 MHz for PAL, and 80 MHz for GAA. Obviously, the allocation may vary substantially from census tract to census tract, but I use the

[37] See, e.g., Raul Katz, "The Future Economic Value of Unlicensed Spectrum," Telecom Advisory Services, LLC, September 11, 2014. See also H. Furchtgott-Roth, "The Economic Value of Property Rights Concepts in Spectrum, Both With and Without Licenses," Hudson Institute Center for the Economics of the Internet, April 4, 2017.

assumption of nationwide allocation to calculate nationwide aggregate market value, consumer surplus, and net present value of consumer surplus of the CBRS spectrum.

In Table 4, I present the adjusted market value of the entire CBRS band based on the assumptions describe above. Depending on the market value of the 2.5 GHz spectrum (varying across columns) and depending on the discount of CBRS spectrum relative to 2.5 GHz spectrum, Table 4 shows that the adjusted market value of the 150 MHz CBRS spectrum ranges from $7.5 to $15.6 billion, even accounting for 80 MHz of GAA with no market value.[38] The vast majority of the measured market value of CBRS is attributable to incumbent governmental users, who generally are not allowed to sell their spectrum. These adjusted market values are roughly 33% - 40% of corresponding values of 150 MHz of 2.5 GHz spectrum.

In Table 5, I present the annual consumer surplus of the entire CBRS band based on the assumptions describe above. Depending on the market value of the 2.5 GHz spectrum (varying across columns) and depending on the discount of CBRS spectrum relative to 2.5 GHz spectrum, Table 5 shows that the annual consumer surplus of the 150 MHz CBRS spectrum ranges from $8 billion to $26 billion.[39] These annual consumer surplus values are roughly 40% - 70% of corresponding values of 150 MHz of 2.5 GHz spectrum. Depending on the discount of CBRS to 2.5 GHz spectrum, which ranges from

[38] GAA has no market value because it assigned free of charge. If the allocation were 20 MHz for incumbent users and 50 MHz for PAL, the adjusted market value of the 150 MHz CBRS spectrum ranges from $3.3 billion to $11.7 billion.

[39] If the allocation were 20 MHz for incumbent users and 50 MHz for PAL, the adjusted consumer surplus of the 150 MHz CBRS spectrum ranges from $3.9 billion to $22.1 billion.

a 50% - 95% discount, much of this annual consumer surplus is not from incumbent users. It is this incremental consumer surplus that is a major part of the economic value of expanding CBRS service in the 3.5-3.7 GHz band.

In Table 6, I present the net present value of consumer surplus of the entire CBRS band based on the assumptions describe above. Depending on the market value of the 2.5 GHz spectrum (varying across columns) and depending on the discount of CBRS spectrum relative to 2.5 GHz spectrum, Table 6 shows that the annual consumer surplus of the 150 MHz CBRS spectrum ranges from $80 billion to $260 billion.[40] These net present values of consumer surplus values are roughly 40% - 70% of corresponding net present values of 150 MHz of 2.5 GHz spectrum.

[40] If the allocation were 20 MHz for incumbent users and 50 MHz for PAL, the adjusted consumer surplus of the 150 MHz CBRS spectrum ranges from $38.8 billion to $221 billion.

Table 1

Estimated net present value of consumer surplus with a 10% discount rate of incumbent CBRS licenses nationwide
Based on the value of 2.5-2.6 GHz spectrum as a lower upper bound
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Equivalent amount of nationwide incumbent spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
5 MHz	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016
10 MHz	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
20 MHz	$29,286	$32,540	$35,794	$39,048	$42,302	$45,556	$48,810	$52,064
30 MHz	$43,929	$48,810	$53,691	$58,572	$63,453	$68,334	$73,215	$78,096
40 MHz	$58,572	$65,080	$71,588	$78,096	$84,604	$91,112	$97,620	$104,128
50 MHz	$73,215	$81,350	$89,485	$97,620	$105,755	$113,890	$122,025	$130,160

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table 2

Estimated net present value of the consumer surplus for five nationwide footprints of 10 MHz PAL license
10% discount rate, Derived from Table B.7
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.450	0.51	0.552	0.63	0.654	0.75	0.756	0.87
2.5-2.6 GHz spectrum	$73,215	$81,350	$89,485	$97,620	$105,755	$113,890	$122,025	$130,160
50% value	$36,608	$40,675	$44,743	$48,810	$52,878	$56,945	$61,013	$65,080
40% value	$29,286	$32,540	$35,794	$39,048	$42,302	$45,556	$48,810	$52,064
30% value	$21,965	$24,405	$26,846	$29,286	$31,727	$34,167	$36,608	$39,048
20% value	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
10% value	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016
5% value	$3,661	$4,068	$4,474	$4,881	$5,288	$5,695	$6,101	$6,508

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table 3

Estimated net present value of the consumer surplus for a nationwide footprint of 80 MHz of GAA
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
2.5-2.6 GHz spectrum	$117,144	$130,160	$143,176	$156,192	$169,208	$182,224	$195,240	$208,256
50% value	$58,572	$65,080	$71,588	$78,096	$84,604	$91,112	$97,620	$104,128
40% value	$46,858	$52,064	$57,270	$62,477	$67,683	$72,890	$78,096	$83,302
30% value	$35,143	$39,048	$42,953	$46,858	$50,762	$54,667	$58,572	$62,477
20% value	$23,429	$26,032	$28,635	$31,238	$33,842	$36,445	$39,048	$41,651
10% value	$11,714	$13,016	$14,318	$15,619	$16,921	$18,222	$19,524	$20,826
5% value	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table 4

Estimated adjusted market value of 150 MHz in the CBRS band
Based on 50 MHz incumbent spectrum, 20 MHz PAL licenses, and 80 MH GAA
Derived from Tables A.2, B.6, and C.4
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust PAL and GAA to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 150 MHz 2.5-2.6 GHz spectrum	$21,965	$24,405	$26,846	$29,286	$31,727	$34,167	$36,608	$39,048
50% value	$8,786	$9,762	$10,738	$11,714	$12,691	$13,667	$14,643	$15,619
40% value	$8,493	$9,437	$10,380	$11,324	$12,268	$13,211	$14,155	$15,099
30% value	$8,200	$9,111	$10,022	$10,933	$11,845	$12,756	$13,667	$14,578
20% value	$7,907	$8,786	$9,664	$10,543	$11,422	$12,300	$13,179	$14,057
10% value	$7,614	$8,460	$9,306	$10,152	$10,999	$11,845	$12,691	$13,537
5% value	$7,468	$8,298	$9,127	$9,957	$10,787	$11,617	$12,447	$13,276

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table 5

Estimated annual consumer surplus for 150 MHz in the CBRS band
Based on 50 MHz incumbent spectrum, 20 MHz PAL licenses, and 80 MH GAA
Derived from Tables A.3, B.7, and C.5
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust PAL and GAA to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 150 MHz 2.5-2.6 GHz spectrum	$21,965	$24,405	$26,846	$29,286	$31,727	$34,167	$36,608	$39,048
50% value	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
40% value	$13,179	$14,643	$16,107	$17,572	$19,036	$20,500	$21,965	$23,429
30% value	$11,714	$13,016	$14,318	$15,619	$16,921	$18,222	$19,524	$20,826
20% value	$10,250	$11,389	$12,528	$13,667	$14,806	$15,945	$17,084	$18,222
10% value	$8,786	$9,762	$10,738	$11,714	$12,691	$13,667	$14,643	$15,619
5% value	$8,054	$8,949	$9,843	$10,738	$11,633	$12,528	$13,423	$14,318

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table 6

Estimated net present value of consumer surplus in the 150 MHz CBRS band
Based on 50 MHz incumbent spectrum, 20 MHz PAL licenses, and 80 MH GAA and 10% discount rate
Derived from Tables A.4, B.8, and C.6
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust PAL and GAA to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 150 MHz 2.5-2.6 GHz spectrum	$219,645	$244,050	$268,455	$292,860	$317,265	$341,670	$366,075	$390,480
50% value	$146,430	$162,700	$178,970	$195,240	$211,510	$227,780	$244,050	$260,320
40% value	$131,787	$146,430	$161,073	$175,716	$190,359	$205,002	$219,645	$234,288
30% value	$117,144	$130,160	$143,176	$156,192	$169,208	$182,224	$195,240	$208,256
20% value	$102,501	$113,890	$125,279	$136,668	$148,057	$159,446	$170,835	$182,224
10% value	$87,858	$97,620	$107,382	$117,144	$126,906	$136,668	$146,430	$156,192
5% value	$80,537	$89,485	$98,434	$107,382	$116,331	$125,279	$134,228	$143,176

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

APPENDIX A

VALUING CBRS SPECTRUM FOR INCUMBENT USERS

In this appendix, I examine the value of CBRS spectrum for incumbent users. First, let me note the difficulty of assessing either the market or consumer value of this particular band of spectrum.

The difficulty of measuring value in this band of spectrum

It is difficult to measure the value of spectrum in the CBRS band for at least the following reasons:

The spectrum is not for sale -- Under current practice, rights to hold licenses, rather than the FCC licenses themselves are actually bought and sold. For CBRS, even the rights to hold licenses for much of incumbent use and General Authorized Access are not available for transactions.

No transactions are contemplated -- Valuing spectrum, or the right to hold licenses, is often for purpose of a transaction. Buyers and sellers will independently obtain advice about the market value of spectrum. The market value of the spectrum is ultimately revealed in an actual transaction for spectrum rights. With the exception of auctions for tens of thousands of Priority Access Licenses on a triennial basis, CBRS spectrum will not be subject to market transactions; rights to use the entire band are unavailable, much less for sale. Actual transactions become both basis for prediction of future prices as well as a test of prior predictions; without the possibility of actual transactions for the entire band, the estimates of market value in this report are

necessarily theoretical. Estimates of market value are presented to indicate market interest in the band rather than to forecast a future transaction.

There are no close spectrum substitutes for the CBRS band -- The CBRS band is not adjacent, or even close in proximity, to other commercial bands. This paper primarily compares CBRS to the EBS and BRS spectrum at 2.5 and 2.6 GHz, physically the nearest bands with similar commercial development possibilities. Even so, the physical characteristics of spectrum at 2.5 GHz are different from characteristics at 3.6 GHz. Many of the potential commercial applications, such as enterprise LTE, could developed in still other spectrum bands.

Full commercial development of the CBRS band is still years away – Although incumbent users continue to use the CBRS band, other entities interested in CBRS await license assignments and equipment certification.

The CBRS band is likely to spawn unpredictable innovations -- In part because it is structured different from other spectrum bands, and in part because as much as 150 MHz of spectrum can be deployed, the CBRS band is likely to have different applications from other bands. Although some specific applications are discussed in this paper, the full range of possible uses is unknowable.

Spectrum values tend to vary substantially by geography -- Much of the discussion about CBRS spectrum value in this report will pertain to national averages. As with all bands of spectrum, the value of CBRS spectrum almost certainly varies substantially by geographic area. More densely populated areas tend to have more valuable spectrum. Similarly, geographic areas with substantial incumbent use likely will have PAL and GAA valuations higher than areas with substantial incumbent use.

For at least all of the reasons above, it is important to view the values of CBRS spectrum as presented in this report not as precise measures but as approximations. The CBRS band will be shown to have substantial value, but the exact measure of that value is today unknowable.

The likely value of CBRS spectrum to incumbent users

The incumbent users and their customers are the consumers of the incumbent CBRS spectrum. The incumbent users have not purchased their spectrum rights, and no secondary market for those spectrum rights is readily available. Thus techniques to measure consumer surplus or consumer welfare based on the market value of spectrum cannot easily be applied. I propose two alternative methods:

1. Avoided costs as an upper bound on incumbent consumer surplus One measure of the commercial value of an asset is the cost of making the current owner equally well off with a different asset. Thus, over more than the past two decades, the federal government has vacated federal spectrum which was then transferred to the FCC for auction in exchange for funding to relocate federal users and acquire new spectrum and equipment for those users. In these instances, the federal government's willingness to be compensated for relocation is an indication that the combined value of compensation for being relocated, plus new equipment, plus the new spectrum, is *greater* than the combined value to the federal government of the vacated spectrum and equipment.

Mathematically, we can represent this relationship as follows:

NPV(Incumbent Spectrum) + NPV(Incumbent equipment and operations)

< NPV(Incumbent Spectrum, Competitive usage) – NPV of relocation cost

– NPV(new spectrum) (1)

In inequality (1), a new competitive provider, facing economic evaluation on the right of the inequality sign, can afford to pay the incumbent user, whose economic calculus is on the left of the inequality. Rearranging terms, we get:

NPV(new spectrum) < NPV(Incumbent spectrum, CBRS: Competitive usage – incumbent usage) – NPV(Relocation cost) – NPV(Incumbent equipment and operations, CBRS) (2)

Or the net present value of new spectrum is worth less than the change in the net present value in the incumbent spectrum reduced by various transactions costs. Under inequality (2), the new competitive user of the incumbent spectrum is better off by compensating the incumbent user, including purchasing the new spectrum on the incumbent's behalf. The reverse logic is also true. We observe that the incumbent users, including federal users, did not vacate the CBRS band. Inequality (2) is reversed as follows:

NPV(new spectrum) > NPV(Incumbent spectrum, CBRS: Competitive usage –incumbent usage) – NPV(Relocation cost) – NPV(Incumbent equipment and operations, CBRS) (3)

In the simplest case, where relocation and equipment costs are zero, the net present value of new spectrum is worth more than the increase in net present value of spectrum between the competitive entrant an the incumbent. The new competitive entrant will not pay to relocate the incumbent user.

We do not observer offers to relocate the federal government to another band—say lease spectrum from Sprint in the 2.5-2.6 GHz band. What we do observe is the federal government's unwillingness to be compensated for relocation is an indication that the combined value of compensation for being relocated, plus new equipment, plus the new spectrum, at say 2.5GHz, is *less* than the combined value to the new entrant of the CBRS spectrum net of paying the incumbent to move.

Hypothetically, a third party could purchase the rights to some portion of the 2.5-2.6 GHz band from Sprint. In terms of bandwidth and frequency, the 2.5-2.6 GHz band is the nearest commercially valued band to the CBRS band. Assuming unrealistically that incumbent plant and equipment could be transitioned costlessly to the 2.5-2.6 GHz band, the *lowest avoided cost upper bound* would simply be the value of the 2.5-2.6 GHz spectrum necessary for the incumbent user in inequality (3). The *highest avoided cost upper bound* would be the value of the 2.5-2.6 GHz spectrum plus the cost of fully replacing all plant and equipment in inequality (3).

As an example, in Table A.1, I present a hypothetical situation with an incumbent user in a geographical area with one million population, using 20 MHz of CBRS spectrum. The

full replacement cost of plant and equipment of the incumbent user is assumed to be $10 million. Based on Wells Fargo data, the value of 2.5-2.6 GHz spectrum in June 2017 ranged from $0.45 to $0.80 per MHz pop with a median value of $0.625 per MHz pop.[41] The lowest upper bound on the avoided cost value of consumer surplus would be 20 million MHz pop x $0.625, or $12.5 million. The greatest upper bound on the avoided cost of consumer surplus would be $12.5 million plus $10 million, or $22.5 million.

Based on the market value for 2.5-2.6 GHz spectrum as estimated by Wells Fargo as a lower upper bound, in Table A.2 I present estimates of the market value of incumbent CBRS spectrum. I provide estimates for equivalents of between 5 MHz and 50 MHz of incumbent CBRS spectrum nationwide. It is unclear exactly how much of the CBRS band will be dedicated to incumbent use. For example, incumbent users may be in 30MHz of spectrum with 30% of the geography of the country, but only interfere with other users 33% of the time. The equivalent might then be 10 MHz of spectrum rather than 30 MHz of spectrum. As seen in Table A.2, the estimated adjusted market value of incumbent CBRS licenses nationwide ranges between $730 million and $13 billion, depending on assumptions about the amount of spectrum dedicated to incumbent use and the underlying value of 2.5-2.6 GHz spectrum.

Economists often measure consumer welfare with *consumer surplus*, the area under a demand curve above the market price. Bazelon and McHenry have noted a regularity in

[41] Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10. Due to shorter range and reduced building penetration, spectrum for incumbent users in the CBRS band may be slightly less valuable than spectrum in the 2.5-2.6 GHz band. I have not made adjustments for this difference.

the market value of spectrum with one year of the consumer surplus value of the spectrum.[42] Thus, if a block of spectrum is worth $1 million, its consumer surplus for one year is also approximately $1 million. In Table A.3, I present the estimated annual consumer surplus of incumbent CBRS spectrum. The values again range between $730 million and $13 billion.

Bazelon and McHenry note a consistency in the ratio of the net present value of all future consumer surplus for spectrum with the market value of the spectrum.[43] At a 5% discount rate, the ratio ranges from 18 – 33; at a 10% discount rate, the ratio ranges from 9 – 17.[44] I will conservatively assume a discount rate of 10% and a ratio of 10. Thus, if the market value of an incumbent CBRS license were $x, the estimated net present value for one year of the spectrum would be $x, and the estimated net present value of all future consumer surplus would be $10x. In Table A.4, I present the estimated net present value of current and future consumer surplus of incumbent CBRS spectrum with a 10% discount rate. The values range between $7 billion and $130 billion.

[42] C. Bazelon and G. McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy," May 2015, pp. 15-17 and Table 3, available at http://www.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf

[43] C. Bazelon and G. McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy," May 2015, pp. 15-17 and Table 3, available at http://www.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf

[44] Ibid.

2. Value of PAL as a lower bound for incumbent consumer surplus The FCC determined that incumbent users have absolute priority relative to PALs. One interpretation is that FCC values the net present value of the consumer surplus of incumbent users as greater than that for PAL users. Below we discuss the calculation of consumer surplus for PALs.

Table A.1

Example of Avoided Costs for Hypothetical Incumbent CBRS User

Bandwidth	20 MHz
Population	1,000,000
Equipment replacement and other non-spectrum related transition costs	$10 million
Median value of 20 million MHz 2.5-2.6 GHz spectrum	$12.5 million
Total avoided cost by not moving	$22.5 million
Lowest upper bound on avoided cost	$12.5 million
Highest uppoer bound on avoided cost	$22.5 million

Table A.2

Estimated adjusted market value of incumbent CBRS licenses nationwide
Based on the value of 2.5-2.6 GHz spectrum as a lower upper bound
(in $millions)

Equivalent amount of nationwide incumbent spectrum	*Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis*							
	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
5 MHz	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302
10 MHz	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
20 MHz	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
30 MHz	$4,393	$4,881	$5,369	$5,857	$6,345	$6,833	$7,322	$7,810
40 MHz	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413
50 MHz	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table A.3

Estimated annual consumer surplus of incumbent CBRS licenses nationwide
Based on the value of 2.5-2.6 GHz spectrum as a lower upper bound
(in $millions)

Equivalent amount of nationwide incumbent spectrum	*Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis*							
	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
5 MHz	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302
10 MHz	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
20 MHz	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
30 MHz	$4,393	$4,881	$5,369	$5,857	$6,345	$6,833	$7,322	$7,810
40 MHz	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413
50 MHz	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016

Source: Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10.

Table A.4

Estimated net present value of consumer surplus with a 10% discount rate of incumbent CBRS licenses nationwide
Based on the value of 2.5-2.6 GHz spectrum as a lower upper bound
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Equivalent amount of nationwide incumbent spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
5 MHz	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016
10 MHz	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
20 MHz	$29,286	$32,540	$35,794	$39,048	$42,302	$45,556	$48,810	$52,064
30 MHz	$43,929	$48,810	$53,691	$58,572	$63,453	$68,334	$73,215	$78,096
40 MHz	$58,572	$65,080	$71,588	$78,096	$84,604	$91,112	$97,620	$104,128
50 MHz	$73,215	$81,350	$89,485	$97,620	$105,755	$113,890	$122,025	$130,160

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

APPENDIX B

VALUING CBRS SPECTRUM FOR PAL LICENSEES

The most comparable spectrum to CBRS PAL with commercial value is the 2.5-2.6 GHz band, largely controlled by Sprint. Much like CBRS PAL, the 2.5-2.6 GHz band offers substantial bandwidth, primarily for unpaired applications. I use a three-step method: (a) estimate the value of 2.5-2.6 GHz spectrum; (b) adjust that value for PAL in CBRS; and (c) estimate the value of consumer surplus.

a. The value of 2.5-2.6 GHz spectrum

Spectrum values are usually measured on a price-per-Mega-Hertz-pop basis, or $ per MHz pop. In my opinion, the most comparable spectrum values for the PAL licenses in CBRS spectrum are, the 2.5-2.6 GHz band. That band can be used for the applications envisioned for PAL. Based on Wells Fargo data, the value of 2.5-2.6 GHz spectrum in June 2017 ranged from $0.45 to $0.80 per MHz pop with a median value of $0.625 per MHz pop.[45]

b. Adjustments for PAL

It is likely inappropriate to compare the value of a PAL in the CBRS band to 10 MHz of spectrum in the 2.5-2.6 GHz band. A PAL in the CBRS has less value than 10 MHz of spectrum in the 2.5-2.6 GHz band for several reasons including:

- Smaller geographic area;

[45] Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10.

- Much shorter duration of licenses;
- Absence of presumption of renewability of licenses;
- Much lower power limits and OOBE limits;
- Incumbent users have priority particularly during certain time periods;
- Higher frequency of spectrum; and
- Administrative costs associated with large number of frequent auctions.

Each of these factors likely reduces the value of PAL relative to licensed 2.5-2.6 GHz spectrum. I do not have an exact adjustment factor, but a discount of between 50% and 95% is plausible. The net result, as shown in Table B.1, is that the value of a PAL license is likely between $0.0225 and $0.40 per MHz pop. The price ranges presented in Table B.1 are averages across all geographic areas in a country, both urban and rural. It is likely that price ranges in certain urban areas may be higher, and price ranges in certain rural areas may be lower.

In Table B.2, I present based on Table B.1 the estimated value of a 10 MHz PAL in a census tract with 4,000 people, slightly less than the size of an average census tract.[46] I use discount factors ranging from 50% -95%. The values of the licenses range from $900 to $16,000. The values may vary further depending on the characteristics of a census tract, with higher values in urban areas and lower values in rural areas.

In Table B.3, I present based on Table B.2 the estimated value of a nationwide 10 MHz PAL for 325.4 million people with discount factors ranging from 50 – 95%. The values

[46] See https://www.census.gov/geo/reference/gtc/gtc_ct.html.

of the licenses range from $73 million to $1.3 billion. In Table B.4, I present the estimated annual consumer surplus for a nationwide 10 MHz PAL. The estimated consumer surplus ranges from $73 million to $1.3 billion. In Table B.5, I present, with a 10% discount rate, the estimated net present value of consumer surplus for a nationwide 10 MHz PAL. The estimated net present value of consumer surplus ranges from $730 million to $13 billion.

There are potentially as many as seven PALs in each census tract. For purposes of this paper, I will assume on average two PALs in each census tract. In Table B.6, I present based on Table B.3 the estimated market value of two nationwide 10 MHz PAL for 325.4 million people with discount factors ranging from 50 – 95%. The market values of the licenses range from $146 million to $2.6 billion. In Table B.7, I present the estimated annual consumer surplus for two nationwide 10 MHz PAL. The estimated consumer surplus ranges from $146 million to $2.6 billion. In Table B.8, I present, with a 10% discount rate, the estimated net present value of consumer surplus for two nationwide 10 MHz PAL. The estimated net present value of consumer surplus ranges from $1.5 billion to $26 billion.

Table B.1

Estimated adjusted value of PAL license on a dollar per MHz pop basis
Derived from Wells Fargo estimate of the value of 2.5-2.6 GHz spectrum

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
50% value	0.225	0.25	0.275	0.3	0.325	0.35	0.375	0.4
40% value	0.18	0.2	0.22	0.24	0.26	0.28	0.3	0.32
30% value	0.135	0.15	0.165	0.18	0.195	0.21	0.225	0.24
20% value	0.09	0.1	0.11	0.12	0.13	0.14	0.15	0.16
10% value	0.045	0.05	0.055	0.06	0.065	0.07	0.075	0.08
5% value	0.0225	0.025	0.0275	0.03	0.0325	0.035	0.0375	0.04

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table B.2

Estimated adjusted market value of a 10 MHz PAL license in a census tract with 4,000 people
Derived from Table B.1

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$18,000	$20,000	$22,000	$24,000	$26,000	$28,000	$30,000	$32,000
50% value	$9,000	$10,000	$11,000	$12,000	$13,000	$14,000	$15,000	$16,000
40% value	$7,200	$8,000	$8,800	$9,600	$10,400	$11,200	$12,000	$12,800
30% value	$5,400	$6,000	$6,600	$7,200	$7,800	$8,400	$9,000	$9,600
20% value	$3,600	$4,000	$4,400	$4,800	$5,200	$5,600	$6,000	$6,400
10% value	$1,800	$2,000	$2,200	$2,400	$2,600	$2,800	$3,000	$3,200
5% value	$900	$1,000	$1,100	$1,200	$1,300	$1,400	$1,500	$1,600

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table B.3

Estimated adjusted market value of a nationwide footprint of 10 MHz PAL license
Derived from Table B.2
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
50% value	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302
40% value	$586	$651	$716	$781	$846	$911	$976	$1,041
30% value	$439	$488	$537	$586	$635	$683	$732	$781
20% value	$293	$325	$358	$390	$423	$456	$488	$521
10% value	$146	$163	$179	$195	$212	$228	$244	$260
5% value	$73	$81	$89	$98	$106	$114	$122	$130

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table B.4

Estimated annual consumer surplus of a nationwide footprint of 10 MHz PAL license
Derived from Table B.2
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
50% value	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302
40% value	$586	$651	$716	$781	$846	$911	$976	$1,041
30% value	$439	$488	$537	$586	$635	$683	$732	$781
20% value	$293	$325	$358	$390	$423	$456	$488	$521
10% value	$146	$163	$179	$195	$212	$228	$244	$260
5% value	$73	$81	$89	$98	$106	$114	$122	$130

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table B.5

Estimated net present value of the consumer surplus for a nationwide footprint of 10 MHz PAL license
10% discount rate, Derived from Table B.4
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
2.5-2.6 GHz spectrum	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
50% value	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016
40% value	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413
30% value	$4,393	$4,881	$5,369	$5,857	$6,345	$6,833	$7,322	$7,810
20% value	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
10% value	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
5% value	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table B.6

Estimated adjusted market value of two nationwide footprints of 10 MHz PAL licenses
Derived from Table B.3
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
50% value	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
40% value	$1,171	$1,302	$1,432	$1,562	$1,692	$1,822	$1,952	$2,083
30% value	$879	$976	$1,074	$1,171	$1,269	$1,367	$1,464	$1,562
20% value	$586	$651	$716	$781	$846	$911	$976	$1,041
10% value	$293	$325	$358	$390	$423	$456	$488	$521
5% value	$146	$163	$179	$195	$212	$228	$244	$260

Source: Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10.

Table B.7

Estimated annual consumer surplus offive nationwide footprints of 10 MHz PAL licenses
Derived from Table B.4
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
50% value	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
40% value	$1,171	$1,302	$1,432	$1,562	$1,692	$1,822	$1,952	$2,083
30% value	$879	$976	$1,074	$1,171	$1,269	$1,367	$1,464	$1,562
20% value	$586	$651	$716	$781	$846	$911	$976	$1,041
10% value	$293	$325	$358	$390	$423	$456	$488	$521
5% value	$146	$163	$179	$195	$212	$228	$244	$260

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

Table B.8

Estimated net present value of the consumer surplus for five nationwide footprints of 10 MHz PAL license
10% discount rate, Derived from Table B.7
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
2.5-2.6 GHz spectrum	$29,286	$32,540	$35,794	$39,048	$42,302	$45,556	$48,810	$52,064
50% value	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
40% value	$11,714	$13,016	$14,318	$15,619	$16,921	$18,222	$19,524	$20,826
30% value	$8,786	$9,762	$10,738	$11,714	$12,691	$13,667	$14,643	$15,619
20% value	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413
10% value	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
5% value	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.

APPENDIX C

VALUING CBRS SPECTRUM FOR GAA USERS

It is conceptually difficult to ascribe an economic value to an asset that has no market price and is largely consumed free of charge.[47] Some assets and services that we consume freely have little economic value, such as an idle thought or a speck of dust. Other assets and services that we consume freely have substantial economic value. There are many examples from the air we breathe to public parks to public roads. Unlicensed spectrum and GAA are assets consumed without charge, but have substantial economic value.

Each census tract has at least 80 MHz of GAA, and potentially as much as 150 MHz of GAA if no one applies for PAL. Before users decide whether to apply for PAL or GAA in the CBRS band, the decision of PAL or GAA is economically distinct from the decision of whether to use unlicensed in a particular band such as 2.4 GHz or 5 GHz. For example, in the decision about whether to use an unlicensed application in 2.4 GHz, using a licensed version of 2.4 GHz is rarely an option. The choice is merely to use either: an unlicensed application in 2.4 GHz; an unlicensed application in a different band; or no application.

[47] For the seminal discussion of public goods, see Paul A. Samuelson, "The Pure Theory of Public Expenditure," *The Review of Economics and Statistics*, Vol. 36, No. 4, 1954, pp. 387-389.

Ex ante, the situation is different for CBRS. Potential users may choose between a license with PAL or no license with GAA. As we have seen, it is at least conceptually possible to value PAL, and therefore, at least *ex ante*, it is possible to value GAA. The value of GAA applications can be viewed in comparison with the value of PAL applications. Demand for PAL represents the willingness of PAL users, direct licensees and their downstream customers, to pay for PAL.[48]

Consumer surplus for PALs is the value that consumers derive from the consumer applications of wireless services using PALs. This consumer surplus is how much more consumers would have been willing to pay for the wireless services and applications beyond what they actually pay. Bazelon and McHenry reviewed major economic studies of consumer surplus and spectrum market value associated with wireless services. They observed that the ratio of annual consumer surplus to spectrum market value in these studies ranges between 1.0 and 1.7. Using a conservative ratio of 1.0, one can find the corresponding annual consumer surplus for a PAL would be its market value. This is how much American consumers, not the PAL licensees, would benefit each year from the PAL spectrum being put to effective use.

The market value of an asset such as license is equal to the net present value of expected future cash flows. If a PAL has a stream of expected cash flows of a constant value of $x and is evaluated at a discount rate of 10%, the NPV of the cash flows, and the value of

[48] C. Bazelon and G. McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy," May 2015, pp. 15-17 and Table 3, available at http://www.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf

license, is $10x. Thus, under the Bazelon and McHenry analysis, we can determine that the *annual* consumer surplus is also $10x, which means that the annual consumer surplus is 10 times the value of the annual expected cash flow.

Next, I consider the demand and consumer surplus for GAA. As discussed earlier, a GAA user must always accept interference from other CBRS users. If prices and costs were the same,[49] a CBRS user would prefer a PAL to a GAA permission, simply to have priority with respect to interference. Consequently, where demand for PAL exceeds the number of available licenses, the demand curve for GAA is likely bounded from above by the PAL demand curve.[50]

Of course GAA incurs no direct payment to the government, and consequently all that will be visible will be demand at the zero price point, or prices adjusted for transaction and administrative costs. For GAA, license revenue is zero as the price paid to the government is zero. But consumer surplus is not correspondingly zero even if the price paid for the GAA permit is zero. The applications that can be adopted with GAA are largely the same as for PAL. I will assume as a first-order approximation that the consumer surplus value of GAA is bounded above by the same consumer surplus value of a PAL in the same geographic area. In geographic areas where PALs are scarce and have positive market value, their value and their consumer surplus will be bid up. In

[49] Transactions and administrative costs can be substantial for either PAL or GAA, although it is not obvious whether they will be greater for PAL or GAA. In any event, these costs will be included in the trade-offs made by CBRS users.
[50] In the instances where there are more PAL licenses than demand, a potential licensee might opt for GAA.

geographic areas with little demand for PALs, GAAs may actually have greater value and greater consumer surplus.

As shown in Table C.1, the market value of GAA for an authorization in a census tract is zero, because a user could always receive authorization to use GAA without payment. But under a wide range of circumstances, a reasonable first-order approximation would set the consumer surplus for a 10 MHz GAA allocation equivalent to the consumer surplus for a 10 MHz PAL. Thus the estimated annual consumer surplus values for a nationwide 10 MHz PAL in Table C.2 are likely a good approximation of consumer surplus for a nationwide 10 MHz GAA assignment. The range is between $73 million and $1.3 billion. Similarly, the estimated net present values of the consumer surplus for nationwide 10 MHz GAA in Table C.3 are between $730 million and $13 billion.

There are at least 80 MHz of GAA in each census tract. For purposes of this paper, I will assume 80 MHz of GAA in each census tract. In Table C.4, I present based on Table C.1 the estimated market value of eight nationwide 10 MHz PAL for 325.4 million people with discount factors ranging from 50 – 95%. The market values of the licenses in each instance are zero. In Table C.5, I present the estimated annual consumer surplus for 80 MHz nationwide GAA. The estimated consumer surplus ranges from $586 million to $10.4 billion. In Table C.6, I present, with a 10% discount rate, the estimated net present value of consumer surplus for nationwide 80 MHz of GAA. The estimated net present value of consumer surplus ranges from $5.9 billion to $104 billion. The net present value is easily in the tens of billions of dollars

Table C.1

Estimated adjusted market value of a 10 MHz GAA authorization in a census tract with 4,000 people

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$18,000	$20,000	$22,000	$24,000	$26,000	$28,000	$30,000	$32,000
50% value	$0	$0	$0	$0	$0	$0	$0	$0
40% value	$0	$0	$0	$0	$0	$0	$0	$0
30% value	$0	$0	$0	$0	$0	$0	$0	$0
20% value	$0	$0	$0	$0	$0	$0	$0	$0
10% value	$0	$0	$0	$0	$0	$0	$0	$0
5% value	$0	$0	$0	$0	$0	$0	$0	$0

Table C.2

Estimated annual consumer surplus of a nationwide footprint of 10 MHz GAA Authorization
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
50% value	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302
40% value	$586	$651	$716	$781	$846	$911	$976	$1,041
30% value	$439	$488	$537	$586	$635	$683	$732	$781
20% value	$293	$325	$358	$390	$423	$456	$488	$521
10% value	$146	$163	$179	$195	$212	$228	$244	$260
5% value	$73	$81	$89	$98	$106	$114	$122	$130

Source: Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10.

Table C.3

Estimated net present value of the consumer surplus for a nationwide footprint of 10 MHz of GAA
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
2.5-2.6 GHz spectrum	$14,643	$16,270	$17,897	$19,524	$21,151	$22,778	$24,405	$26,032
50% value	$7,322	$8,135	$8,949	$9,762	$10,576	$11,389	$12,203	$13,016
40% value	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413
30% value	$4,393	$4,881	$5,369	$5,857	$6,345	$6,833	$7,322	$7,810
20% value	$2,929	$3,254	$3,579	$3,905	$4,230	$4,556	$4,881	$5,206
10% value	$1,464	$1,627	$1,790	$1,952	$2,115	$2,278	$2,441	$2,603
5% value	$732	$814	$895	$976	$1,058	$1,139	$1,220	$1,302

Source: Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10.

Table C.4

Estimated adjusted market value of a 80 MHz GAA authorization in a census tract with 4,000 people

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$18,000	$20,000	$22,000	$24,000	$26,000	$28,000	$30,000	$32,000
50% value	$0	$0	$0	$0	$0	$0	$0	$0
40% value	$0	$0	$0	$0	$0	$0	$0	$0
30% value	$0	$0	$0	$0	$0	$0	$0	$0
20% value	$0	$0	$0	$0	$0	$0	$0	$0
10% value	$0	$0	$0	$0	$0	$0	$0	$0
5% value	$0	$0	$0	$0	$0	$0	$0	$0

Table C.5

Estimated annual consumer surplus of a nationwide footprint of 80 MHz GAA Authorization
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discuount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Value of 2.5-2.6 GHz spectrum	$11,714	$13,016	$14,318	$15,619	$16,921	$18,222	$19,524	$20,826
50% value	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413
40% value	$4,686	$5,206	$5,727	$6,248	$6,768	$7,289	$7,810	$8,330
30% value	$3,514	$3,905	$4,295	$4,686	$5,076	$5,467	$5,857	$6,248
20% value	$2,343	$2,603	$2,864	$3,124	$3,384	$3,644	$3,905	$4,165
10% value	$1,171	$1,302	$1,432	$1,562	$1,692	$1,822	$1,952	$2,083
5% value	$586	$651	$716	$781	$846	$911	$976	$1,041

Source: Wells Fargo, "Wireless Spectrum Primer, Second Edition," June 21, 2017, Exhibit 10.

Table C.6

Estimated net present value of the consumer surplus for a nationwide footprint of 80 MHz of GAA
(in $millions)

	Wells Fargo estimate of value of 2.5 GHz spectrum on a $/MHz pop basis							
Discount factors to adjust CBRS to 2.5 GHz spectrum	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
2.5-2.6 GHz spectrum	$117,144	$130,160	$143,176	$156,192	$169,208	$182,224	$195,240	$208,256
50% value	$58,572	$65,080	$71,588	$78,096	$84,604	$91,112	$97,620	$104,128
40% value	$46,858	$52,064	$57,270	$62,477	$67,683	$72,890	$78,096	$83,302
30% value	$35,143	$39,048	$42,953	$46,858	$50,762	$54,667	$58,572	$62,477
20% value	$23,429	$26,032	$28,635	$31,238	$33,842	$36,445	$39,048	$41,651
10% value	$11,714	$13,016	$14,318	$15,619	$16,921	$18,222	$19,524	$20,826
5% value	$5,857	$6,508	$7,159	$7,810	$8,460	$9,111	$9,762	$10,413

Source: Wells Fargo, “Wireless Spectrum Primer, Second Edition,” June 21, 2017, Exhibit 10.