Spectrum Sharing

Taxonomy and Economics

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Table of Contents

Executive Summary

As demand for more complex wireless technologies increases, so does the demand for spectrum suitable for wireless broadband services. This is true for both government and commercial users. On the commercial side, Cisco famously predicted that U.S. mobile data traffic will grow 9-fold between 2012 and 2017. On the federal side, users have over 240,000 frequency assignments and their needs are increasing. Sharing between federal and commercial users will be a key component of the strategy to meet growing demands for spectrum.

Allocating shared spectrum "efficiently," however, requires balancing competing demands to assign the spectrum use rights to the user(s) who value(s) them most. In principle, when managing the trade-offs from competing demands, efficient spectrum management policy should seek to maximize total social and economic value of spectrum, subject to the priorities set by policymakers. When applied to spectrum sharing proposals, these principles of efficient spectrum allocation lead to two findings. First, spectrum sharing should only be implemented if the foregone value to the primary user from sharing is less than the added value to the secondary user(s). Second, spectrum sharing is efficient when the cumulative value to all users is higher than the potential value to a single user.

The economic value of spectrum today is simply the present value of the cumulative future profits that can be earned using the resource. When spectrum is shared amongst multiple users, this cumulative profit includes the total profits for all services deployed on the spectrum (including the value created by public uses.) The profits from a band of spectrum are the net revenues, or revenues less investment and operating costs, of deploying the spectrum band. For each user, the derived value of spectrum is based on the additional value, or net profit for commercial users, that spectrum adds to a particular spectrum based service. The value of a band of spectrum, then, is related to the value created by all users.

Since the value of spectrum is defined by the profitability of the spectrum based services deployed, any factor that impacts the residual profits of using a band of spectrum will impact the value of that band. This includes restrictions to use rights that reduce potential ***revenues*** from service, increase the ***costs*** of deployment, or create added ***uncertainty*** about the potential for realizing future profits. The effect from sharing on each of these factors is likely to diminish the profitability, and hence value, of a band a band of spectrum.

There are several different types of spectrum sharing currently proposed or in use.

- Under ***geographic sharing***, a given spectrum user's transmissions are limited to a predefined service area. Several proposals are already being considered for geographic sharing arrangements between federal and commercial users in the 1695-1710 MHz band and the 1755-1850 MHz band.

- Another commonly considered type of sharing is ***temporal sharing***. In this case, two or more users would share access to the same band of spectrum in the same geographic area, but at different times. Such arrangements can be divided into two major categories: predictable and random. Under a ***predictable temporal sharing*** regime, one user agrees not to transmit during particular pre-defined times to accommodate the other user's services. The impact of predictable sharing on the value to a given user depends, in part, on the timing, frequency and certainty of when interruptions might occur. ***Unpredictable or random temporal sharing*** occurs when the secondary user may have to stop using the specific spectrum on short notice or without warning. This type of sharing was initially proposed for the 700 MHz D Block. Typically, the greater the sharing obligations and the less predictable they are, the greater the diminution in value for the user(s) that have to accommodate or yield in their use to allow the sharing.

- ***Coordinated sharing*** refers to sharing arrangements where two or more users are using the same band of spectrum in the same geographic area at the same time. To prevent harmful interference, users' devices must detect what other devices are operating in the same geographic area and on the same frequencies, and then respond accordingly. The two potential mechanisms for coordination are databases and cognitive radios. Cognitive radio networks or devices automatically detect devices in its vicinity and coordinate usage in response. Alternatively, spectrum databases register their location and devices, and then identify which spectrum is available for use. This is the approach already in use for unlicensed devices operating in the television bands.

- ***Uncoordinated Rule-Based sharing*** refers to situations where rules of use are designed to prevent harmful interference. Uncoordinated sharing typically occurs over unlicensed spectrum in which devices that meet a particular set of criteria are allowed to transmit over the spectrum. This approach is typically employed for low power devices, such as baby monitors and wireless microphones, WiFi, and radio astronomy.

We numerically illustrate the impact of sharing on spectrum value through a series of examples, both hypothetical and grounded in CSMAC recommendations. For example, geographic exclusion areas would reduce the potential value of a band. We show that for the 1695 MHz – 1710 MHz band, excluding 12% of the population in the currently proposed exclusion zones could reduce the value of the band by 16%, but relocating some of the exclusion zones from urban to rural areas would only reduce the value of the band by 7%. This option increases total value so long as the cost of relocating the exclusion zones is less than the value created. As an alternative to exclusion zones, it may be possible to use additional filters on base stations. We illustrate this impact of increased cost on spectrum value by modeling a 20% capital cost increase for 15% of the network impacted by exclusion zones. In this case, that added cost reduces the value of the spectrum by 11%, an option that preserves more value than the 16% loss associated with the currently proposed exclusion zones, but potentially less (depending on the relocation costs) than the 7% loss when the exclusion zones are relocated to less populated areas. In a separate, illustrative, analysis we show how increased uncertainty in the form of a 1% increase in the firm's cost of capital can reduce the value of a band of spectrum by 29%.

It is widely accepted that until Federal users internalize the costs associated with their spectrum use, they have little incentive to use spectrum more efficiently or support proposals to share their spectrum. If federal users paid for spectrums use, they would internalize the cost associated with holding spectrum assignments that prevent other productive uses of the frequencies. Recognizing the costs of spectrum through a federal fee would incentivize federal users to adjust their usage to reduce costs. While there are limitations to a fee-based approach, it would require government users to incur some cost for spectrum usage. By imposing a spectrum based fee, the cost of spectrum based services for federal users will reflect the use of this scarce resource. The question is: *what should the fee be tied to?* Consistent with the principle that government spectrum users should consider the forgone economic value of spectrum deployed for their services, we suggest that a federal user fee should be based on the commercial value of spectrum. By tying the fee for federal spectrum to spectrum's commercial price, federal users would be incurring the foregone economic value or opportunity cost of the spectrum in deploying these federal services. A fee based on the commercial value of spectrum would require that federal users at least acknowledge this opportunity cost of the spectrum use and publically argue that the value of their use of the spectrum exceeds this opportunity cost.

I. Introduction

As demand for more complex wireless technologies increases, so does the demand for spectrum suitable for wireless broadband and WiFi services. This is true for both government and commercial users. In 2013, Cisco predicted that U.S. mobile data traffic will grow 9-fold between 2012 and 2017.[1] Consumers are using their mobile devices more than ever. According to a recent study, in 2013, the average American spent 2 hours and 21 minutes per day on mobile devices using non-voice mobile activities, up from only 24 minutes in 2010.[2] This demand is likely to continue rising.

Demand for Federal allocations continues to expand as well. As of September 2012, federal users had over 240,000 frequency assignments[3] and their needs are increasing.[4] Superstorm Sandy and the Mid-Atlantic Derecho only reinforced the need for accurate satellite weather tracking and hardened wireless infrastructure that can sustain the force of brutal storms. Even before the

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1 *See*, Cisco, "VNI Mobile Forecast Highlights, 2012 – 2017: United States – 2017 Forecast Highlights," at: http://www.cisco.com/web/solutions/sp/vni/vni_mobile_forecast_highlight/index.html#~Country (last visited 6 Aug. 2013).

2 Of this time in 2013, 47.5% was spent on a smartphone, 44.8% was spent on a tablet, and 7.7% was spent on a feature phone. In 2010, 41.5% of the time was spent on a smartphone, 4.3% was spent on a tablet, and 54.3% was spent on a feature phone. *See*, "Digital Set to Surpass TV in Time Spent with US Media," *eMarketer*, 1 Aug. 2013, available at: http://www.emarketer.com/Article/Digital-Set-Surpass-TV-Time-Spent-with-US-Media/1010096 (last visited 12 Aug. 2013). *See also*, Alex Colon, "Pretty soon we'll all be watching tablets instead of televisions," *Gigaom*, 2 Aug. 2013, available at: http://gigaom.com/2013/08/02/pretty-soon-well-all-be-watching-tablets-instead-of-televisions/ (last visited 12 Aug. 2013).

3 *See*, GAO, "Spectrum Management, Incentives, Opportunities, and Testing Needed to Enhance Spectrum Sharing," *GAO-13-7*, November 2012, (herein, "GAO 13-7 Spectrum Sharing), at page 5.

4 *See*, Testimony of Mr. Karl Nebbia, Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administration, U.S. Department of Commerce, Before the Subcommittee on Communications and Technology, Committee on Energy and Commerce, United States House of Representatives, Hearing on "Equipping Carriers and Agencies in the Wireless Era," 27 June 2013, (herein, "Nebbia, 2013"), available at: http://www.ntia.doc.gov/speechtestimony/2013/testimony-associate-administrator-nebbia-hearing-equipping-carriers-and-agencie (last visited 12 Aug. 2013).

nationwide interoperable public safety network is built, local public safety groups foresee a growing need for video surveillance and mobile wireless video support for rapid response.[5]

Spectrum sharing between federal and commercial users will be a key component of the strategy to meet these growing demands. All else equal, any spectrum user would prefer exclusive use of spectrum. However, as the value of spectrum increases, creating or keeping a band of spectrum dedicated to a single user is increasingly costly. Consequently, both incumbent users who want to maintain their existing assignments and new users looking for available frequencies will, by necessity, need to seriously consider sharing an allocation of spectrum.

In considering spectrum sharing opportunities, however, it is important to assess if a given sharing proposal improves the overall management of radio spectrum. That is, if the value sacrificed by a single user is worth the benefits of allowing multiple users access to the spectrum. Some sharing proposals will leave all users worse off and such proposals should be rejected. Between commercial users, where sharing would be valuable, we generally expect the parties to make efficient agreements. With respect to sharing between commercial and federal users, however, they have divergent incentives. In such cases, spectrum managers must decide the appropriate allocation.

This paper focuses on how to evaluate efficient sharing between federal and non-federal users. We recognize, however, that the issue of sharing—and the analytic framework developed herein—is broader than federal and non-federal users. We set out an analytic framework for evaluating when spectrum sharing proposals improve welfare, and when they do not. We illustrate our proposed approach by evaluating the potential impact on value from the spectrum sharing recommendations made by the Commerce Spectrum Management Advisory Committee ("CSMAC") for the 1690 MHz – 1710 MHz and 1755 MHz – 1850 MHz bands.

To motivate the efficient use of federal spectrum, policymakers are now calling for incentives for federal users. One proposal has been a fee based assignment for federal users. The question is: *what should the fee be tied to?* We suggest that the fee should be based on the value of spectrum for commercial users. This approach ensures that government spectrum users consider the

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5 *See*, Michael Catalano, Spectrum Supply and Demand, Washington Post Live, 18 June 2013, remarks, webcast available at http://www.washingtonpost.com/postlive/conferences/spectrum (last visited 2 Sept. 2013).

forgone economic value of spectrum deployed for their services. As part of a fee based approach, however, federal users must be assured that they will be able to acquire spectrum assignments when they have a justifiable need. Otherwise, they may not have an incentive to relinquish unused spectrum, regardless of spectrum based fees.

II. Economic Factors Critical to Spectrum Sharing

To understand the effect of sharing on spectrum value, we start by looking at the economic factors critical to spectrum sharing. The spectrum sharing arrangement determines how a band of spectrum can be deployed by two or more users. Such division of use rights only improves the efficiency of spectrum use overall if the total value from sharing exceeds the value from an exclusive user.

A. Spectrum Sharing Policies

Now, more than ever, spectrum is a truly scarce national resource that must be allocated, or reallocated, as efficiently as possible to further our national interests. Some of these interests include growing the national economy, improving access to educational resources, supporting local public safety, and strengthening national security and defense.[6] However, achieving this myriad of goals is particularly challenging when it requires balancing a number of conflicting interests. Several spectrum blocks have been identified as lynchpins in the National Broadband Plan's (NBP's) goal of repurposing 500 MHz of spectrum to commercial use, including:[7]

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6 *See*, The White House Office of the Press Secretary, *Presidential Memorandum – Expanding America's Leadership in Wireless Innovation*, 14 June 2013, (herein, "Presidential Memorandum, 2013"), available at: http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovatio (last visited 11 Aug. 2013). *See also*, Nebbia, 2013, at section 2.

7 These bands have been identified in the Job Creation Act, in the NBP, by NTIA, and in various FCC regulatory proceedings. *See*, H.R. 3630, "Middle Class Tax Relief and Job Creation Act," 22 Feb. 2012, Section VI, Subtitle D; National Broadband Plan, Chapter 5, available at http://www.broadband.gov/plan/5-spectrum/ (last visited 2 Sept. 2013). *See also,* FCC Notice of Proposed Rulemaking and Order, GN Docket 12-354, 12 Dec. 2012 (herein, "NPRM 3.5 GHz"); FCC Notice of Proposed Rulemaking, ET Docket 13-49, 20 Feb. 2013 (herein, "NPRM 5 GHz"); FCC Notice of Proposed Rulemaking and Order on Reconsideration, GN Docket 13-185, 23 July 2013 (herein, "NPRM 1.7 GHz").

- 1695-1710 MHz band;
- 1755-1850 MHz band;
- 3550-3650 MHz band; and
- 5350-5470 MHz and 5850-5925 MHz bands.

At the same time, existing federal users have ongoing—and sometimes expanding—needs for wireless services as well as costs associated with moving to alternative bands. In many cases, federal users who relinquish spectrum must continue providing the same missions, either through alternative technology or new assignments. Moving federal assignments, however, may be costly and time consuming. A 2012 NTIA report found that moving Federal users out of the 1755-1850 MHz band would cost approximately $18 billion and take 10 years.[8] Similarly, the NTIA Fast Track Report found that the 1695-1710 MHz band could be largely cleared, with the exception of exclusion zones around NOAA weather satellite receiver base stations.[9] Where clearing spectrum outright is not feasible, policymakers are looking to sharing as a solution.

Spectrum sharing, which can be defined as the "cooperative use of common spectrum" for disparate uses, is not a new concept.[10] Until recently, however, spectrum sharing was generally confined to private license holders, federal or other governmental users, or unlicensed users, rather than across these types of users. Cooperative sharing among a group of (usually similar) users is generally easier to achieve through existing mechanisms. For instance, sharing between commercial or other private licensed users is either built into the allocation by the FCC—say, through geographic sharing that results from different licensees being assigned different sub-national licenses—or negotiated on a contractual basis between parties. Federal spectrum assignments are acquired through an application and review process. Spectrum sharing between federal assignment holders is then based on mission, need, and ability to coexist. Sharing between different types of users, however, creates a more complicated cooperation problem,

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8 *See,* NTIA, "An Assessment of the Viability of Accommodating Wireless Broadband in the 1755–1850 MHz Band," March 2012, page iii.

9 *See,* NTIA, "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands," October 2010, (herein, "NTIA Fast Track Report").

10 *See*, GAO 13-7 Spectrum Sharing, at page 7. Some scholars—such as Thomas Hazlett—note that even exclusively licensed spectrum is shared with the users of the network. However, for the purposes of this paper, we distinguish between sharing between users and sharing between spectrum assignees and/or licensees.

because the actual uses of the spectrum are likely to be different. This creates more potential scenarios for users to interfere with each other, as the parties' incentives are not unified.

B. CHALLENGES OF SPECTRUM SHARING

In light of the demands and the challenges of relocating existing users, commercial/Federal spectrum sharing was initially proposed as a compromise to open bands to commercial users without uprooting federal users. The July 2012 President's Council of Advisors on Science and Technology ("PCAST") Report presented sharing as a superhighway of diverse users cooperatively using the same radio waves.[11] To begin work on implementation, CSMAC was tasked with evaluating the potential for sharing in these targeted bands between commercial and Federal users.

It is important to recognize, however, that spectrum sharing between different types of users creates several unique hurdles. First, spectrum sharing limits the value of spectrum to individual users and, thereby, has the potential to reduce the cumulative value of spectrum to all users. Second, divergent motivations, lack of unifying incentives to share, and security concerns are likely to make negotiating between Federal and commercial uses time consuming and difficult.[12]

Sharing necessarily limits how users can use spectrum, and thereby limits the value of spectrum for individual users. Spectrum use rights can be defined in many dimensions—geography, time, direction, etc.[13]—but the specific definition or rights is not key here. Rather, for sharing, what is important is that such use rights can be disaggregated. The economic value of a spectrum license for a license holder is equal to the NPV of future profits from deploying spectrum based services.[14] This value depends critically on what a user can do with a license or assignment. Limiting uses restricts what an individual user can do with the spectrum. By separating what

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11 *See*, PCAST, "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," Report to the President, July 2012, Executive Summary page vii.

12 *See*, for example, the concerns raised in CSMAC Meetings, and Separate Statements of Working Group Members, Harold Furtchgott Roth, and Janice Obuchowski, each released 19 August 2013, available at: http://www.ntia.doc.gov/category/csmac (last visited 2 Sept. 2013).

13 *See,* for example, Robert Matheson and Adele C. Morris, "The technical basis for spectrum rights: Policies to enhance market efficiency," Brookings Institution, March 3, 2011, page 8.

14 *See*, Coleman Bazelon and Giulia McHenry, "Spectrum Value," *Journal of Telecommunications Policy*, forthcoming, (herein, "Bazelon and McHenry (2013)").

users can do, or when they can do it, spectrum sharing limits the potential use and economic value for the commercial license holder or welfare created by a non-commercial user.

Successful spectrum sharing depends critically on assigning the use rights for each user to ensure that they can use the spectrum effectively to provide a valuable service. Moreover, depending on how the use rights are allocated, spectrum sharing may reduce the cumulative value of the spectrum for all users.

C. Framework for Spectrum Sharing Decisions

Allocating shared spectrum "efficiently" requires balancing competing demands to assign the spectrum use rights to the user(s) who value(s) them most. Spectrum managers must take into account all of the legitimate demands for spectrum from government, commercial, and other non-commercial users. These include public safety, military protection, promoting education and scientific research, and spurring economic growth and prosperity in the private sector.

In principle, when managing the trade-offs from competing demands, efficient spectrum management policy should seek to maximize total social and economic value of spectrum, subject to the priorities set by policymakers. There are at least two types of value that may be created by spectrum based services for policymakers to consider: economic value driven by the potential profits from deploying the spectrum, and social value created by the non-commercial spectrum based applications. Both of these types of value should be considered when making spectrum allocation decisions.

Nevertheless, there is often an inherent tradeoff between economic efficiency and other public policy objectives. Economic efficiency maximizes the contribution of spectrum to creating economic value and consumer welfare from commercial services. As described below, the economic value of spectrum is derived from the expected profits of services deployed on that spectrum. Maximizing the economic value of spectrum is essentially equivalent to maximizing the potential profits derived from the spectrum. To align with public policy objectives, policy makers must impose binding constraints on commercial users, thereby reducing the economic value of spectrum. However, restrictions on the use of spectrum limit the potential profits available to a given user. At the extreme, exclusive use of a spectrum band for government uses implies that no private economic value will be directly derived from that band. Below that extreme, any restrictions that limit the use of spectrum are liable to diminish its value.

The social welfare from non-economic public policy goals is also difficult to quantify in economic terms. We know what a tank costs, but it is difficult to articulate the monetary value a tank contributes to our national defense. In the absence of a useful metric for quantifying social welfare from policy goals, an alternative approach is to assess the forgone economic value from deviating from the economic value maximizing spectrum allocation. A policy that deviates from the economically efficient spectrum allocation is only worth pursuing if the benefits are expected to outweigh the foregone value. While this does not strictly maximize the return on social policies, it does ensure that such policies are only undertaken when they are believed to be at least as valuable as efficient commercial allocations.

This also implies that policymakers should endeavor to maximize economic efficiency, because it creates the most economic value. This efficiency should only be sacrificed for explicit policy objectives that are considered more socially valuable than the forgone value of using the spectrum efficiently. Based on these principles, it is crucial to know the costs and forgone opportunity associated with any allocation policy when trying to achieve efficient spectrum management, or evaluate proposed departures from efficient uses of spectrum.

These principles of efficient spectrum allocation should apply when evaluating spectrum sharing proposals, because any specific proposal inevitably balances the value and requirements between two or more competing users. First, spectrum sharing should only be implemented if the foregone value to the primary user from sharing is less than the added value to the secondary user(s). Second, spectrum sharing is efficient when the cumulative value to all users is higher than the potential value to a single user. In a commercial world, economists believe that the price mechanism generally achieves efficient allocations, even in the context of sharing. A commercial license holder is only willing to sell the partial rights to the spectrum license if she values that portion of the spectrum less than what another user is willing to pay for those rights. With respect to non-commercial allocations, even if we cannot value the benefit of a particular non-commercial use of spectrum, policy makers should consider and evaluate the foregone commercial value from its use.

III. Taxonomy of Spectrum Sharing

There are several different types of spectrum sharing currently proposed or in use. Below we categorize four broad types of sharing, and offer some current or proposed examples of each type.

The four categories of spectrum sharing are: geographic, temporal, coordinated, and uncoordinated rule-based. In addition to the types of sharing, the extent of sharing and compatibility of users is also key to evaluating the impact of a specific sharing arrangement on spectrum value.

A. Geographic Sharing

Under geographic sharing, a given spectrum user's transmissions are limited to a predefined service area. As discussed below, several proposals are already being considered for such an arrangement between federal and commercial users in the 1695-1710 MHz band and the 1755-1780 MHz band.[15] In fact, geographic sharing is already commonly used in the commercial and federal spectrum bands. FCC licenses are mostly divided regionally, resulting in individual users having transmission rights in different geographic areas of the U.S. In these cases, the FCC has concluded that the loss in value from not issuing a single national license is worth the added flexibility in allowing regional differences in license holders.

B. Temporal Sharing, Predictable and Random

Another commonly considered type of sharing is temporal sharing. In this case, two users would share access to the same band of spectrum in the same geographic area, but at different times. There are several ways in which a temporal sharing arrangement might be constructed.[16] Such arrangements can be divided into two major categories: predictable and random. Under a predictable temporal sharing regime, one user agrees not to transmit during particular pre-defined times to accommodate the other user's services. Such sharing might vary by frequency and regularity.

The impact of predictable sharing on the value to a given user depends, in part, on the timing, frequency and certainty of when interruptions might occur. For instance, AM radio spectrum is shared between daytime and dominant 24-hour broadcasters. Many of the daytime broadcasters are required to reduce or turn off their service at night, allowing the dominant 24-hour station to

[15] *See*, NPRM 1.7 GHz, paragraphs 53 through 76.

[16] For instance, one user may be considered a priority user who essentially dictates when they plan to use the spectrum, there may be a preset contract stipulating usage, users may negotiate a time allocation, or users may set up a mechanism to pay for time.

broadcast to a larger footprint as its nighttime propagation widened its footprint.[17] Alternatively, a general user might have access to a band of spectrum, except when it is needed during rocket launches. To the extent that the timing of predictable sharing can also be negotiated, to occur at times that are acceptable to both parties, the value lost may be even lower.

Unpredictable or random sharing occurs when the secondary user may have to stop using the specific spectrum on short notice or without warning. This type of sharing was initially proposed for the 700 MHz D Block. Typically, the greater the duration and less predictable the sharing obligations, the greater the diminution in value for the secondary user(s).

C. Coordinated Sharing

Coordinated sharing refers to sharing arrangements where two or more users are using the same band of spectrum in the same geographic area at the same time. To prevent harmful interference, coordinated sharing requires that users detect what devices are operating in the same geographic area and on the same frequencies, and then respond accordingly. The two potential mechanisms for coordination are databases and cognitive radios.

Coordinated sharing prevents harmful interference through the use of intelligent radio networks or devices. Depending on the technology, cognitive networks or handsets are designed to detect the presence of other potentially interfering devices and decide whether or not it can operate. These devices may also be able to search for alternative frequencies that would be available for transmission. These technologies are still developing, however, and are not widely available for commercial deployments. An alternative is a spectrum database in which users register their location and devices, and can then identify which spectrum is available for use. This is the approach developed to share the television bands with unlicensed devices.

D. Uncoordinated Rule-Based Sharing

Uncoordinated Rule-Based sharing refers to situations where rules of use are designed to prevent harmful interference. Uncoordinated sharing typically occurs over unlicensed spectrum in

17 *See*, http://www.fcc.gov/encyclopedia/why-am-radio-stations-must-reduce-power-change-operations-or-cease-broadcasting-night (last visited 17 December 2013).

which devices that meet a particular set of criteria are allowed to transmit over the spectrum.[18] Since this type of sharing is rule-based, as long as all users follow the rules for the band, unlike in the case of cognitive sharing, there is no further need for coordination among the users. Examples of this type of sharing include low power devices, such as baby monitors and wireless microphones, WiFi, and even radio astronomy.

IV. Drivers of Spectrum's Economic Value

In order to understand the inherent tradeoffs and forgone economic value for a public policy goal, it is necessary to understand what drives the economic value of spectrum. Spectrum is not a store of value; rather, it is an input into the production of valued services. A clear understanding of these principles will illuminate how particular sharing arrangements are likely to impact spectrum value.

A. Value of Spectrum is the Cumulative Value of Services Deployed

Similar to all scarce resources, the value of spectrum is determined by the economic value generated by its deployment. For assets that are in limited supply, this concept is typically understood as economic rent, or net profitability attributable to the scarce asset. Since spectrum is in fixed supply, it is a limiting factor in the production of wireless services. That is, less spectrum results in less, or higher cost, wireless service; more spectrum results in more, or lower cost, services. Since spectrum availability limits the availability of wireless services, much of the value created from the wireless services is attributed to the spectrum itself. This effect is similar to how a coffee shop on a busy corner gets more business than if it was on a side street, but will also pay for these extra sales in higher rents. The additional sales are due to the location, which then justifies higher rents. Likewise, differences in the potential profits of various spectrum bands imply differences in the value of those bands. When rules on the use of spectrum alter the potential profitability from its use, the value of the spectrum will change accordingly.

[18] Unlicensed refers to the type of allocation, whereas the low power limits and other rules are how the unlicensed bands mitigate harmful interference. Similar mitigation techniques, however, can also be deployed on licensed bands. *See*, Thomas Hazlett and Coleman Bazelon, "Market Allocation of Radio Spectrum," ITU Workshop on Market Mechanisms for Spectrum Management, Geneva, January 2007.

The economic value of spectrum today is simply the present value of the cumulative future profits that can be earned using the resource. When spectrum is shared amongst multiple users, this cumulative profit includes the total profits for all services deployed on the spectrum. For each user, the derived value of spectrum is based on the additional value, or net profit, that spectrum adds to a particular spectrum based service. The value of a band of spectrum, then, is related to the profits that can be made from using it.

These profits are derived from the net revenues, or revenues less investment and operating costs, of deploying the spectrum band. Deploying a band of spectrum for any service requires both permission to use the spectrum and capital expenditures for the infrastructure necessary to transmit services. What a network operator can pay to secure the spectrum rights to licensed spectrum is determined by the profits from service, net of the capital and operating costs of the specific spectrum band. Each operator cannot pay more than the value of those profits (or the operator would lose money on the venture). However, the operator is also unlikely to pay much less for licensed spectrum, otherwise a competing operator would be willing to pay more for access to the same spectrum rights. Similarly, the operator will forgo the spectrum if it can identify a more profitable, or less costly, alternative way to provide the same service without the spectrum asset. For instance, a wireless broadband provider might invest in additional capital to re-farm its existing spectrum holdings rather than acquire access to new frequencies. Therefore, the value of a given spectrum license is limited by the profits that can be made with its use, which are, in turn, limited by the profits from alternative ways to provide the same service.

Since offering spectrum based services typically requires substantial upfront investments in infrastructure and compatible technology, the time dimension is important. Consequently, the value of a spectrum license must be based on the net present value (NPV) of future profits. This value is driven by more than the profits earned in the next year or two. As with any capital investment, the net return of investing in a band of spectrum will be realized over time. The value of the investment and expected stream of profits depends critically on the timing of this stream of returns. The NPV of a capital investment represents the cash value today of the expected stream of net returns (revenues minus costs) that an investment is expected to yield over its lifetime. The NPV accounts for the interest that investment would have otherwise accrued over the investment period, and the future uncertainty of a particular use. The present value of any investment by user i is equal to the sum of the present value of each annual net return or cash flow, $\left(R_t - C_t\right)$, discounted by the rate of return (r_t) for that year:

$$NPV_i = \sum_{t=0}^{\infty} \frac{R_{it} - C_{it}}{\left(1 + r_t\right)^t} \quad (1)$$

With respect to shared spectrum, the cumulative economic value of the band is equal to the sum of all future expected net profits for all users:

$$NPV = \sum_{i=1}^{n} \sum_{t=0}^{\infty} \frac{R_{it} - C_{it}}{\left(1 + r_t\right)^t} \quad (2)$$

B. Changes in Residual Profit Drive Changes in Spectrum Value

Since the value of spectrum is defined by the profitability of the spectrum based services deployed, any factor that impacts the residual profits of using a band of spectrum will impact the value of that band. This includes restrictions to use rights that reduce potential revenues from service, increase the costs of deployment, or create added uncertainty about the potential for realizing future profits. Each of these factors is likely to diminish the profitability of a band.

To the extent that the profitability of spectrum based services vary, so too will the value of spectrum that make those services possible. Geographic areas with dense populations where spectrum services are heavily used are more valuable than less populated areas where demand for services is lower. Although more difficult to observe, temporal differences in value are driven by the peak or off-peak hours of use.

V. The Impact of Sharing on Spectrum Value

In this section we apply the taxonomy in Section III and principles from Section IV to discuss how sharing will likely impact the value of spectrum to a single user and the cumulative value to all users. Below we review the potential types of sharing, and describe the key impacts on value for each.

A. When Sharing Restricts How One User Would Otherwise Use a Band of Spectrum it Reduces the Profits for that User

In essence, spectrum sharing necessarily creates costs and restricts revenues, compared to exclusive use of the same band. Sharing may restrict what, when or where services, infrastructure, or capital are deployed. For instance, if spectrum sharing requires more complex technology, such as cognitive radios, the added cost and uncertainty of developing and deploying those technologies will limit profitability compared to using a band that did not require such added costs. To the extent that sharing limits the type or quality of allowable services—for instance by intermittently interrupting service—it curbs the potential revenues from services.

Sharing involves trade-offs. Allowing a new user into a band will likely diminish what the existing user can do. Consequently, the lost value to an individual user should be part of the consideration for evaluating whether sharing spectrum is efficient. Never the less, sharing may still be less costly or more socially and economically valuable than moving existing users. This depends on whether the gains to those who benefit by the partial use of the spectrum are greater than the losses to those who would otherwise have exclusive access to the band.

To understand the impact of sharing on spectrum value, consider equation (1) above. The profitability of a spectrum band depends on the revenues, costs, and discount rate associated with that spectrum.[19] Figure 1 summarizes the types of factors that are likely to affect each of these components of spectrum value. For instance, revenues typically depend on the factors related to the wireless service provided, including the type of service, its quality and scope. Sharing, in turn, may alter any one of these factors, thereby reducing the total profitability of the service. Similarly, sharing may increase the cost of deployment, or uncertainty. Below we explore each of these sets of factors in more detail.

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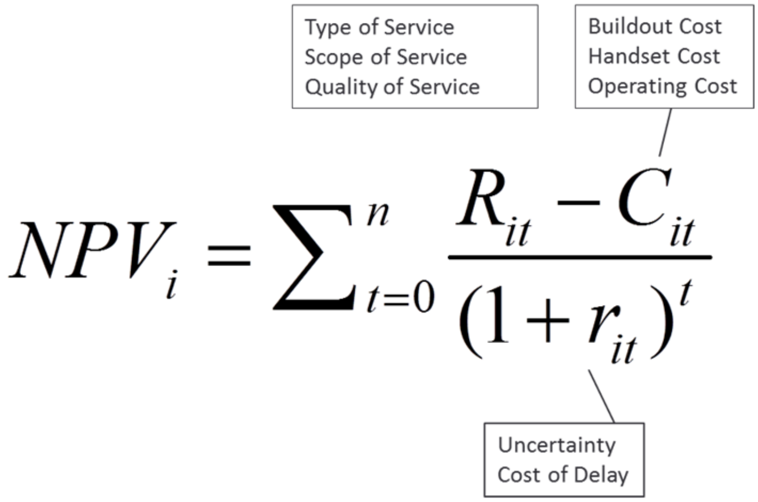
19 Note that increases and decreases in value are not simply about costs. Restrictions that affect revenues (or the missions for public sector users) also impact value. Assessing the forgone revenue of sharing is essential to understanding the costs and benefits of a shared band.

Figure 1. Components of Spectrum Value



$$NPV_i = \sum_{t=0}^{n} \frac{R_{it} - C_{it}}{(1 + r_{it})^t}$$

1. Sharing may decrease revenues by restricting use

Since revenues flow directly from the potential services deployed, revenues from shared spectrum will decrease with a change in the types of deployable services. The extent to which sharing might alter revenues depends on whether allowable services are impacted. At one extreme, sharing a band may require a license holder to change the type of service they provide. For instance, while it may be possible to deploy an exclusive use band for wireless broadband services, sharing that same band may reduce the potential services to intermittent unlicensed devices only. One example of this would be the TV Broadcast spectrum band, which could be repurposed for exclusive wireless broadband use. As a secondary user to TV Broadcasters, however, deploying broadband is limited to white spaces, which in the current environment implies relatively limited spectrum availability and lower revenue expectations as a result.

Even if sharing does not alter the type of wireless service, it is likely to reduce the expected revenues from service and resulting value of the band. Moreover, this reduction in value is likely to be *increasing* relative to the extent of sharing; more sharing results in even greater discounts to the value relative to the proportion of spectrum shared. Setting aside the impact on the type of service discussed above, spectrum sharing is likely to have two effects on revenue even when the same type of service is deployed. First, a smaller *scope* of services will reduce revenues in proportion to the diminution in service. Second, any decreased *quality* of services will further reduce revenue. While the first factor should decrease revenues relative to forgone service, the second factor decreases revenues for the remaining services network-wide.

All else equal, when sharing restricts the scope of services deployed, it reduces the value associated with the use right that has been carved out. This reduction in revenue is generally proportional to the value of the restricted service. For instance, if sharing limits services in an area that comprises 30% of the revenues from a nationwide license, revenues will be lost for 30% of the market. A similar effect would occur if sharing limited service hours, or capacity. The reduction in revenues is proportional to the value driven by that portion of the market forgone. This suggests that limiting daytime service in top markets will have a greater impact on revenue than restricting service in the middle of the night or remote locations.

In addition to restricting scope of service, sharing can reduce the *quality* of spectrum based services, resulting in diminished revenues and profit margins for the services deployed. This reduction in quality is a critical component of the loss in value from shared spectrum. For example, temporary interruptions in service caused by temporal sharing are likely to reduce the quality of wireless broadband services. Likewise, if geographic exclusion zones result in limited access to services in certain areas, this would reduce the quality of service. In fact, empirical evidence from auction receipts and academic research suggests that there is a premium for larger contiguous spectrum holdings.[20]

Once these two factors are combined, the impact on the value of the band is likely to be proportionally greater than the value captured by the excluded area. Tables 1 and 2 present

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[20] For instance, De Vries and Chan (2010) found that the price of spectrum in an auction is proportional to (the license population)^1.1. Moreover, they found an aggregation premium of about 13% between regional economic area ("REA") licenses and the substantially smaller economic area ("EA") licenses. (See, J. Pierre de Vries and Cheng-Yu Chan, "Edge License Discounts in Cellular Auctions," Presented at The 38th Research Conference on Communication, Information and Internet Policy (TPRC 2010), 1-3 Oct. 2010, available at http://ssrn.com/abstract=1988429, pages 17-18.) The FCC applied a nationwide spectrum premium of 5% in Nextel spectrum swap. (*See*, FCC, Report and Order, Fifth Report and Order, Fourth Memorandum Opinion and Order, and Order, FCC 04-168, Released 6 Aug. 2004, para. 297.)

Holding a single aggregated license area can be less costly to build, and more reliable roaming network than would be feasible by aggregating a network from disaggregated spectrum holdings.

illustrative examples of the value reduction from geographic and temporal sharing assuming the total value of an exclusive nationwide 10 MHz spectrum block is $3.12 billion.[21]

Geographic. By creating geographic exclusion zones, sharing results in reduced revenues from a smaller coverage area and a discount to the overall revenues because it cannot be a nationwide network. Table 1 illustrates the effect of a geographic exclusion zone that represents 15% of the nationwide coverage on a value weighted basis.[22] Even before a reduction in quality, the value of this band would be 15% lower based on the revised footprint and resulting reduced scope of services. For illustrative purposes, we assume a premium for nationwide coverage of 5%, although it may well be higher.[23] With this assumption, the value to the user of the shared band would be further reduced to $2.5 billion. In total, sharing 15% of the value weighted area, results in a 19% reduction in the value of the band.

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21 For the ease of our illustrative example, we suppose the value of this band is $1.00 per MHz-Pop and the total population is 312 million. The unit price or value of flexible use or wireless broadband spectrum is typically represented in terms of "MHz-pops," which is equal to the product of the MHz of the spectrum band and the total population covered. The total value is then equal to $1*312 million pops*10 MHz. This price is not based on our assessment of the any spectrum bands.

22 As discussed above, spectrum value varies regionally and temporally. For instance, the value of spectrum is higher in New York City than most rural areas on both a total value and a MHz-pop basis. For more explanation of value weights and methods for deriving weights, see Bazelon and McHenry (2013).

23 See footnote 20.

Table 1. Illustrative Example of Geographic Sharing

[A]	MHz		10
[B]	Population		312,000,000
[C]	Spectrum Price	$	1.00
[D]	Nationwide Value	$	3,120,000,000
[E]	Value Weighted Exclusion		15%
[F]	Value Excluded	$	468,000,000
[G]	Value with Nationwide Premium	$	2,652,000,000
[H]	Nationwide Premium		5%
[I]	Shared Spectrum Value	$	2,525,714,286
[J]	Total Discount to Shared Spectrum		19%

Notes and Sources:
The Brattle Group Analysis.
[D]: [A] x [B] x [C].
[F]: [D] x [E].
[G]: [D] - [F].
[I]: [G] / (1 + [H]).
[J]: 1 - ([I] / [D]).

Temporal. With respect to temporal restrictions, there may be even more severe penalties from unpredictable interruptions. While there is less empirical evidence about the effect of temporal interruptions, the experience of the 700 MHz D-Block from FCC Auction 73 suggests that the risk of unpredictable temporal interruptions drastically reduces the value of spectrum.[24] It is very difficult to operate a reliable voice network when it is unclear when the service will work. In such a case, unpredictable service interruptions are likely to drastically limit the potential services and revenues of a band. As the severity of service interruptions and diminished footprints increases, the quality discount is likely to increase.

Table 2 presents an illustrative example of temporal sharing. Suppose temporal sharing requires a one hour, unpredictable service interruption every day. As a result, the band may only be usable for non-voice data services, as opposed to voice and data broadband service. If ARPU for

24 For more information on the 700 MHz D-Block, see Coleman Bazelon, "Too many goals: Problems with the 700 MHz auction," Information Economics and Policy 21 (2009), pages 115–127.

tablet data-only services is half that of voice and data services,[25] then the potential for service interruptions cuts the value of the band in half, from $3.12 billion to $1.56 billion. We assume the exclusion of an hour of time at midnight is an approximately 2% loss, and the exclusion of an hour of time at noon is a little over a 5% loss.[26] These value weighted exclusion times have the effect of reducing the total value of the interrupted spectrum to 51% and 53% of its original value, respectively. To the extent that losing service at midnight for an hour effects the quality of the service less, the total discount to the shared spectrum value may be lower.

Generally, the extent to which temporal sharing is limited to infrequent, off-peak, predictable interruptions, it is likely to reduce the scope of value-weighted services affected, and allow for higher quality services. Less intrusions results in higher expected revenues for the same level of capacity and, as a consequence, greater value. The more frequent, unpredictable, or inconvenient the interruptions are the greater reduction in spectrum value.

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25 Analyst reports suggest that data revenue per user is a little less than half of postpaid ARPU. *See*, for example, Bank of America Merrill Lynch, Wireline & Wireless Telecom Services, 16 May 2011, pages 24-25.

26 Based on the level of data traffic in North America at noon and midnight as estimated by MIT SENSEable City Lab. See P Cruz and C. Ratto, "How the world uses its phone," Wired UK, 2013, pages 34-35.

Table 2. Illustrative Example of Temporal Sharing

[A]	Exclusive Spectrum Value	$	3,120,000,000
[B]	Voice and Data ARPU	$	50
[C]	Data Only ARPU	$	25
[D]	Data Only Service Discount		50%
[E]	Interruptible Service Spectrum Value	$	1,560,000,000
	One Hour Exclusion - Midnight		
[F]	Value Weighted Time of Exclusion		2%
[G]	Value Excluded	$	31,096,345.51
[H]	Interrupted Spectrum Value	$	1,528,903,654
[I]	Total Discount to Shared Spectrum		51%
	One Hour Exclusion - Noon		
[J]	Value Weighted Time of Exclusion		5%
[K]	Value Excluded		$82,923,588
[L]	Interrupted Spectrum Value	$	1,477,076,412
[M]	Total Discount to Shared Spectrum		53%

Notes and Sources:
The Brattle Group Analysis.
[D]: 1 - ([C] / [B]).
[E]: [A] x (1 - [D]).
[F]&[J]: Based on MIT, SENSEable City Lab, 'How the world uses its phone,' 2013.
[G]: [E] x [F].
[H]: [E] - [G].
[I]: 1 - ([H]/[A]).
[K]: [E] x [J].
[L]: [E] - [K].
[M]: 1 - ([L]/[A]).

2. Sharing may increase costs of avoiding interference with other users

Referring back to Figure 1, the value of spectrum will decrease with added operating costs and capital expenditures. Whether *coordinated sharing* or *uncoordinated rule based sharing*, users may have to make additional investments to mitigate interference.[27] With a greater chance for interference, spectrum sharing may necessitate additional filters and more costly base stations or handsets, reduced power levels and more cell sites, and connections to a spectrum management

[27] *Geographic sharing* and *temporal sharing* can also lead to additional costs, with effects similar to those described in this section.

database. In addition, if sharing arrangements necessitate using additional bands of spectrum for deployment, there may be additional fixed costs. These added costs begin even before deployment, requiring more intensive development and research efforts. When sharing requires lower power levels, it increases the number of cell sites and resulting cost of deployment. Complex cognitive sensing arrangements, where a secondary user must automatically detect when to shut off, will take substantial capital and investment, as will connectivity to databases or servers that facilitate sharing.

Consequently, depending on the arrangement, sharing is likely to increase both the upfront cost of deployment and the ongoing cost of operations. As costs increase, cash flows and expected profits diminish, and the resulting spectrum license value will decrease. However, unlike revenues, it is not clear that the discount to value is necessarily increasing relative to the severity of the restriction.

Table 3 offers an illustrative example of how the added costs are likely to reduce cash flows and profitability of spectrum based services. Suppose the sharing arrangement requires additional filters on base stations. Based on the cost of development and installation, suppose these added costs increase the capital investment by 10%, and require an additional 5% in operating expenditures related to base station equipment. The increased capital costs are represented as an increase in the amortized capital expenditures, whereas increased operating costs are represented as an increase in service costs. Based on a review of public financial statements from wireless carriers,[28] suppose net cash flow for a wireless carrier is 15%, while amortized capital costs are 15% of revenues, the cost of equipment is 15% of revenues, and the cost of service is 25% of revenues. As shown in Table 3, based on these assumptions, a 10% increase in capital costs and 5% increase in service costs reduces net cash flows by 18% to 12% of revenues, reducing spectrum value by a similar amount.

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28 This assumption is generally based on the cash flows observed in the public financial filings of U.S. wireless carriers.

Table 3. Illustrative Example of Added Sharing Costs

	Basic Wireless Network Cash Flow Assumptions	Factor
[A]	Cost, amortized capital (% of initial revenue)	15%
[B]	Cost, service (% of initial revenue)	25%
[C]	Cost, equipment (% of initial revenue)	15%
[D]	Cost, SGA (% of initial revenue)	30%
[E]	Total Cost (% of initial revenue)	85%
[F]	Net Cash Flow (% of initial revenue)	15%
	Financial Adjustment	
[G]	Change in Cost, amortized capital	10%
[H]	Change in Cost, service	5%
	Implied Adjusted Network Cash Flow	
[I]	Cost, amortized capital (% of initial revenue)	17%
[J]	Cost, service (% of initial revenue)	26%
[K]	Cost, equipment (% of initial revenue)	15%
[L]	Cost, SGA (% of initial revenue)	30%
[M]	Total Cost (% of initial revenue)	88%
[N]	Net Cash Flow (% of initial revenue)	12%
[O]	Discount to Net Cash Flow	18%

Notes and Sources:
The Brattle Group Analysis.
[A]-[D]: Based off of 2011 Income Statements of Verizon, Sprint, and AT&T.
[E]: Sum of [A]-[D].
[F]: 1 - [E].
[G]-[H]: Changes in cost as a share of revenue.
[I]: (1 + [G]) x [A].
[J]: (1 + [H]) x [B].
[K]: [C].
[L]: [D].
[M]: Sum of [I]-[L].
[N]: 1 - [M].
[O]: ([F] - [N]) / [F].

3. Sharing may increase uncertainty of the profitability of a project

As discussed above, the NPV of a spectrum service is driven by the cash flows, the timing of those cash flow, and the cost of investment. To the extent that sharing introduces delays or adds time for development when compared to using exclusive spectrum, sharing reduces the NPV of any given spectrum deployment.[29] All types of spectrum sharing require several steps that are not otherwise required to deploy an exclusive band. First, users have to investigate the potential interference issues and negotiate cooperative terms of use. Next, users must develop technologies, including filters, cognitive radios and handsets that operate within the parameters of the sharing arrangement. These negotiations and development efforts could be both costly and lengthy. In addition, sharing potentially creates new uncertainties, for instance, when spectrum will be available and whether prohibitive interference will arise. These will also reduce the NPV from spectrum based services and, in turn, reduce the value of the spectrum assignment. Table 4 presents an illustration of the reduction in value from a delay in deployment and increase in uncertainty. Combining a one year delay in deployment and a one percentage point increase in the cost of capital, results in a 29% discount to the NPV and spectrum value.

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[29] It is worth noting that sharing has the potential to speed reallocations compared to waiting to redeploy incumbent users.

Table 4. Illustrative Example of Increased Capital Cost and Delay

	Basic Wireless Network Cash Flow Assumptions	Factor
[A]	Cost, amortized capital (% of initial revenue)	15%
[B]	Cost, service (% of initial revenue)	25%
[C]	Cost, equipment (% of initial revenue)	15%
[D]	Cost, SGA (% of initial revenue)	30%
[E]	Total Cost (% of initial revenue)	85%
[F]	Net Cash Flow (% of initial revenue)	15%
	NPV Assumptions	
[G]	Cost of Capital (%)	7%
[H]	Year Cumulative NPV of Cash Flow Turns Positive	7
[I]	Steady State Growth (%)	3%
[J]	NPV as a Multiple of Year 5 Cash Flow	16.5
	Adjusted NPV Assumptions	
[K]	Cost of Capital (%)	8%
[L]	Year Cumulative NPV of Cash Flow Turns Positive	8
[M]	Steady State Growth (%)	3%
[N]	NPV as a Multiple of Year 5 Cash Flow	11.8
[O]	**Total Discount to NPV**	**29%**

Notes and Sources:
The Brattle Group Analysis.
[A]-[D]: Based off of 2011 Income Statements of Verizon, Sprint, and AT&T.
[E]: Sum of [A]-[D].
[F]: 1 - [E].
[G]: Based on Telecommunications, Services sector cost of capital, http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/wacc.htm, accessed 10/30/13.
[H]: Build Out - Annual Cash Flow, Base WACC Scenario.
[I]: Brattle assumptions.
[J]: (1 + [I])^([H] - 5) / (([G] - [I]) x (1 + [G])^[H]).
[K]: Assumed higher WACC.
[L]: One year delay from [H].
[M]: Assumed revenue growth rate.
[N]: (1 + [M])^([L] - 5) / (([K] - [M]) x (1 + [K])^[L]).
[O]: ([J] - [N]) / [J].

In practice, changes in the three components of spectrum value are not mutually exclusive. To some extent, there are potential tradeoffs between increasing costs, reducing revenues and increasing uncertainty. When facing a geographic interference zone, carriers may either try to maintain service by installing costly filters, or forgo revenues in those areas. Moreover, shared spectrum may result in a combination of increased revenues, costs and uncertainty. Figure 2 provides a brief description of the different types of services which might be impacted by sharing.

Figure 2. Potential Impacts from Spectrum Sharing

Type of Sharing	Reduced Baseline Profitability	Reduced Revenue	Increased Costs	Added Uncertainty
Geographic	Services may be limited.	Reduced scope of service; no nationwide premium.	Increased costs due to interference; lower demand increases per unit cost.	
Temporal: Predictable	Services may be limited.	Reduced scope of service; reduced quality of service.	Increased costs due to interference.	
Temporal: Random	Services likely limited by unpredictability.	Reduced scope of service; further reductions in service quality.	Added network cost to accommodate randome interruption.	Lack of service predictability increases uncertainty.
Coordinated	Potential uses limited.	Revenues limited by service.	Substantial ecosystem development costs; added infrastructure and device costs.	Unpredictable service availability; ecosystem uncertainty; historically mixed results.
Uncoordinated Rule-Based	Restricted to low power uses; limited potential for service-based revenue.			

Source: The Brattle Group Analysis.

B. EFFICIENCY OF SHARING

As explained above, the total value of a band of spectrum is the sum of the values for each use. If the reduction in value to each shared use is such that the sum of these uses is less than the total value from a single exclusive use, then sharing is inefficient. Put differently, if the value lost to the highest value user is greater than the value gained by all other users, spectrum sharing is inefficient. In the context of sharing between federal and commercial users, the value lost to the highest valued commercial use, or combination of commercial shared users, is essentially the foregone value or cost to freeing (or keeping) that spectrum for a federal use. If this cost is greater than the social value of the federal service, or if there is a more cost effective way to provide the same public service, then sharing would be inefficient.

Conversely, if the cumulative value from shared uses is greater than the highest value to a single user, then sharing is efficient. Further, if value lost from commercial uses is less than the social value of the federal service, and there is no more cost-effective way to provide the service, then sharing between federal and commercial users is efficient.

VI. Illustrative Examples: Impact of Sharing on Spectrum Value

This section uses illustrative examples based on the CSMAC Working Groups 1 (WG-1) and 3 (WG-3) findings to demonstrate how various sharing proposals are likely to impact the value of spectrum. The purpose of each example is to illustrate how both the type and extent of sharing impacts the value of spectrum in that arrangement. Moreover, as described above, different types of sharing are likely to impact the value through different components of the NPV equation. These examples illustrate how the relationship between each component of profit impacts value.

A. CSMAC WG-1: Geographic Sharing in the 1695–1710 MHz Band

This section uses illustrative examples based on CSMAC WG-1 to demonstrate how sharing is likely to impact the value of spectrum, and how several mitigation techniques could increase the value of the band. As this illustration shows, both the type and extent of sharing impacts the value of spectrum in that arrangement.

Background. After NTIA released its Fast Track Report, WG-1 was tasked with evaluating the potential for harmful interference between meteorological satellite ground stations and future commercial wireless broadband operations, particularly Long-Term Evolution (LTE) technology. NOAA operates orbital satellites in the 1695-1710 MHz band and geostationary weather satellites in the adjacent 1675-1695 MHz band. These two constellations utilize at least 27 earth station locations that would require protection from harmful interference if commercial LTE base stations operated in the 1695-1710 MHz band.[30]

Based on its evaluation, WG-1 recommends geographic protection zones around each of these 27 satellite earth stations. According to WG-1, these protection zones comprise approximately 10% of the 2010 U.S. population, including nine top 100 mobile wireless markets representing approximately 8% of the U.S. population.[31] This proposal was a refinement to the NTIA Fast Track Report proposal to entirely exclude commercial service from 18 zones representing 13% of

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30 *See*, CSMAC, Final Report: Working Group 1 – 1695-1710 MHz Meteorological-Satellite, (herein "WG-1 Final Report"), 23 July 2013, Appendix 1.1.

31 *See*, CSMAC, Working Group 1 (herein "WG-1 Report (6/2013)"), 18 June 2013, page 4. *See,* also, *Id.* As discussed below, our analysis found that these zones comprise approximately 9% of the 2010 U.S. population, and 8% in top 100 markets. For our analysis, we use these values.

the population.[32] As proposed, these protection zones would be areas in which commercial wireless services would not be permitted, unless the commercial licensee could coordinate with NTIA and FCC to ensure that there would be no harmful interference. Clearing the technical and regulatory hurdles to coordinate LTE operations is still uncertain and potentially costly, but likely feasible.

WG-1 also identifies several potential opportunities to further mitigate the impact of these protection zones, which they recommended for further analysis. First, to eliminate the need for sharing in the most valuable markets, it may be possible to move certain earth stations to lessen the population affected and impact on commercial value.[33] Second, coordinating operations with the geostationary satellites in 1675-1695 MHz may be possible by improving receiver filtering of adjacent band interference.[34] Third, depending on the location, type of satellite operation and specifics of the receiver, there may be potential for temporal sharing between orbital satellites and commercial LTE operations in these zones.[35] It is still not clear whether sharing operations would be possible predictably or randomly. While all three mitigation options may increase the potential revenue from operating the wireless broadband spectrum, they also increase the cost of deploying the spectrum. Below we evaluate the forgone value of the exclusions zones, and potential value from the WG-1 proposals for mitigating the interference issues.

Analysis. As discussed above, the size, location and timing of geographic sharing affects the value of spectrum. To illustrate, we will first compare the value of the spectrum as if it were a complete nationwide band to the value of the remaining spectrum outside the protection zones. For purposes of illustrating the effect of sharing, we adopt a value of spectrum for these bands of $1/MHz-pop.[36] While the protected area represents approximately 9%[37] of the population, not all population is equally valuable. Given the areas in top 100 markets, the reduction in value of the commercial spectrum if normal LTE operations are allowed in the protection zones

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32 *See*, *Ibid.*, page 5.

33 *See*, WG-1 Final Report, pages 5 – 6.

34 *See*, *Ibid.* Appendix 5-1.

35 *See*, *Ibid.* Appendix 5-1 and 5-2.

36 The spectrum value adopted herein is a reasonable approximation, but not intended to be a precise estimate of value.

37 WG-1 reports that the protected areas cover 10% of national population, but our analysis of their data indicate that only 9% of the population is covered. We use our analysis of population throughout.

represents closer to 12% of the value. Next, we consider the potential value regained from relocating satellite base stations out of top 100 markets. Finally, we consider the mitigation strategy of adding filters to base stations or mobile receivers and using part of the protected zones around geostationary satellite earth stations.

1. Exclusion zones

Strict exclusion from operating in these protection zones is likely to have two negative effects on the spectrum value. While the protected area represents approximately 9% of the population, given the areas in top 100 markets, the reduction in commercial spectrum value if all LTE operations are prohibited in the protection zones 12%. Moreover, depending on the nationwide premium, since the band is no longer nationwide, the value of the spectrum decreases by 5% or more.

Table 5 below illustrates the potential reduction in value of wireless broadband spectrum that results from excluding these areas from service. Based on the assumptions above, excluding these areas would result in 16% lower spectrum value than if it were dedicated to exclusive use by wireless broadband users. If, for example, the value were $4.7 billion for a nationwide exclusive band, the lost value would be $750 million or 16%, leaving $3.9 billion of value for the shared spectrum.

Table 5. Illustrative Example of 1695-1710 MHz Value with Exclusion Zones

		Effect on Value
	No Exclusions	
[1]	Population	312,400,577
[2]	MHz-Pop	4,686,008,655
[3]	Value including Nationwide Premium	$4,686,008,655
	Loss from Exclusions	
[4]	Excluded Population	27,946,166
[5]	MHz-Pop Excluded	419,192,490
[6]	Premium for Relative Value of Locations	32%
[7]	Total Value Lost from Excluded Population	$553,631,024
[8]	% Total Value Lost from Excluded Population	12%
[9]	Additional Loss of Nationwide Premium	$196,779,887
[10]	Total Value Lost	$750,410,911
[11]	% Total Value Lost	16%

Notes and Sources:
The Brattle Group Analysis.
[1]: Total US population, from 2010 Census data, by county.
[2]: [1] x 15 MHz of spectrum.
[3]: [2] x estimated national average $/MHz-Pop ($1.00).
[4]: Exclusion zones from CSMAC Working Group 1 (WG-1) Report, 18 June 2013, 1695-1710 MHz, Meteorological-Satellite, p. 4. Excluded population is the population of census blocks included in protection radius.
[5]: [4] x 15 MHz of spectrum.
[6]: Relative value of excluded population to national average. Based on CMA licenses in Auctions 66 and 73.
[7]: [5] x (1 + [6]) x estimated national average $/MHz-Pop ($1.00).
[8]: [7] / [3].
[9]: ([3] - [7]) x price x (1 - (1 / (1 + nationwide premium))), assuming an average price of $1.00 and a nationwide premium of 5%.
[10]: [7] + [9].
[11]: [10] / [3].

2. Move exclusion zones to less populated areas

WG-1 also identifies several potential opportunities to further mitigate the impact of these protection zones, which they recommend for further analysis.[38] One of these proposals is to eliminate the need for sharing in the most valuable markets by relocating certain earth stations

38 *See*, WG-1 Final Report, Appendix 5.

to less populated areas. The 9 protection zones in top 100 markets represent approximately 7%[39] of the U.S. population. Table 6 below illustrates the change in value to the band if these sites were moved to areas within the same or neighboring state.[40] Rather than estimate an exact location for the relocated site, we assume that the population density excluded around the site is equal to the average population density for that state.[41] If these sites could be moved to relatively rural areas, the affected population would be even lower.

As illustrated in Table 6, the total population excluded after relocation would 56% less. This would have several effects on value. First, fewer pops are excluded, increasing the MHz-pops and value of the usable spectrum. Second, by replacing some high-valued urban areas with low-valued rural areas, the relative value of the restricted areas could be approximately 27% lower than the national average spectrum value. By comparison, the relative value of the spectrum in the existing areas is 32% higher than the national average. As a result, the total value lost to the nationwide spectrum value if the nationwide premium is lost is 7%, or $351 million based on our assumptions above. If the excluded population after relocation is sufficiently small to permit the nationwide premium to remain, the lost value would be only 3%, or $133 million based on our assumptions above. This mitigation would make sense if the relocation costs were less than the value gained from the relocations.

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39 While our analysis found that 7% of the exclusion zone population was in top 100 markets, WG-1 found that 8% of the nationwide population was in top 100 markets. We continue to use our analysis.

40 All sites are assumed to remain in the same state except for the Suitland MD site, which we assumed this could move to Virginia.

41 To estimate the population of the excluded area, we calculated: protection area based on maximum protection distance x average state population per square km.

Table 6. Illustrative Example of 1695-1710 MHz Value Relocating Sites in Top 100 Market

		Effect on Value
	No Exclusions	
[1]	Population	312,400,577
[2]	MHz-Pop	4,686,008,655
[3]	Value including Nationwide Premium	$4,686,008,655
	Original Exclusion Zones	
[4]	Total Value Lost	$750,410,911
[5]	% Total Value Lost	16%
	Moving Zones in Top 100 Markets to State Average Locations	
[6]	Excluded Population	12,172,298
[7]	MHz-Pop Excluded	182,584,475
[8]	Premium for Relative Value of Locations	-27%
[9]	Total Value Lost from Excluded Population	$133,779,126
[10]	% Total Value Lost from Excluded Population	3%
[11]	Additional Loss of Nationwide Premium	$216,772,835
[12]	Total Value Lost	$350,551,960
[13]	% Total Value Lost	7%

Notes and Sources:
The Brattle Group Analysis.
[1]: Total US population, from 2010 Census data, by county.
[2]: [1] x 15 MHz of spectrum.
[3]: [2] x estimated national average $/MHz-Pop ($1.00).
[4]: See Table 5, [10].
[5]: [4] / [3].
[6]: Exclusion zones from CSMAC Working Group 1 (WG-1) Report, 18 June 2013, 1695-1710 MHz, Meteorological-Satellite, p. 4. Sites at Suitland, MD (VA); Miami, FL; Hickam AFB, HI; Cincinnati, OH; St. Louis, MO; Omaha, NE; Sacramento, CA; Kansas City, MO; Knoxville, TN are replaced with implied covered pops based on average state population density and exclusion area size.
[7]: [6] x 15 MHz of spectrum.
[8]: Relative value of excluded population to national average. Based on CMA licenses in Auctions 66 and 73.
[9]: [7] x (1 + [8]) x estimated national average $/MHz-Pop ($1.00).
[10]: [9] / [3].
[11]: ([3] - [9]) x price x (1 - (1 / (1 + nationwide premium))), assuming an average price of $1.00 and a nationwide premium of 5%.
[12]: [9] + [11].
[13]: [12] / [3].

3. Partial use in protected zones with filters

Finally, it may be possible to operate in some protection zones by improving adjacent band receiver filtering on LTE base stations. While this would increase the scope of service, it would also increase the cost of deployment in these areas. To illustrate the effect of this type of cost, we assume that OOBE filtering would increase the cost of cell sites and network operating costs by 20%, which would apply to the approximately 15% of the network that is inside the exclusion zone.[42] As shown in Table 7, below, based on these illustrative added costs, the profitability of the commercial spectrum, and resulting value, would be approximately 11% lower than if it were an exclusive band. This suggests that filtering would be more valuable than losing access to the spectrum entirely, which would reduce the spectrum value by 16%.

42 Given the relative value of the excluded areas, we assume that roughly 15% of the nationwide network would be built in these protection zones. If filtering were to add an additional 20% to the capital expenditure and operating costs in exclusion areas, this would imply a 3% increase in total capital and operating expenditures: 1 + 0.15 x 0.20 = 1.03.

Table 7. Illustrative Example of 1695-1710 MHz Value with Filter Costs

	Basic Wireless Network Cash Flow Assumptions	Factor
[A]	Cost, amortized capital (% of initial revenue)	15%
[B]	Cost, service (% of initial revenue)	25%
[C]	Cost, equipment (% of initial revenue)	15%
[D]	Cost, SGA (% of initial revenue)	30%
[E]	Total Cost (% of initial revenue)	85%
[F]	Net Cash Flow (% of initial revenue)	15%
[G]	NPV as a Multiple of Cash Flow	16.5
	Financial Adjustment	
[H]	Change in Cost, amortized capital and service	3%
	Implied Adjusted Network Cash Flow	
[I]	Cost, amortized capital (% of initial revenue)	15%
[J]	Cost, service (% of initial revenue)	26%
[K]	Cost, equipment (% of initial revenue)	15%
[L]	Cost, SGA (% of initial revenue)	30%
[M]	Total Cost (% of initial revenue)	86%
[N]	Net Cash Flow (% of initial revenue)	14%
[O]	Discount to Net Cash Flow	8%
[P]	NPV as a Multiple of Cash Flow	15.9
[Q]	Discount to NPV Multiple	4%
[R]	Total Discount to NPV	11%
[S]	Initial Total Value	$4,686,008,655
[T]	**Value Lost from Increased Costs**	**$536,044,354.55**

Notes and Sources:
The Brattle Group Analysis.
[A]-[D]: Based off of 2011 Income Statements of Verizon, Sprint, and AT&T.
[E]: Sum of [A]-[D].
[F]: 1 - [E].
[G]: (1 + growth rate)^(year cumulative cash flow turns positve - 5) / ((WACC - growth rate) x (1 + WACC)^year cumulative cash flow turns positve), with a growth rate of 3%, year cumulative cash flow turns positive of 7, and WACC of 7%.
[I]: [A] x (1 + [H]).
[J]: [B] x (1 + [H]).
[K]: [C].
[L]: [D].
[M]: Sum of [I]-[L].
[N]: 1 - [M].
[O]: ([F] - [N]) / [F].
[P]: (1 + growth rate)^(year cumulative cash flow turns positve - 5) / ((WACC - growth rate) x (1 + WACC)^year cumulative cash flow turns positve), with a growth rate of 3%, year cumulative cash flow turns positive of 8, and WACC of 7%.
[Q]: ([G] - [P]) / [G].
[R]: 1 - (1-[O]) x (1-[Q]).
[S]: See Table 5, [3].
[T]: [R] x [S].

B. CSMAC WG-3: Temporal and Geographic Sharing in 1755–1780 MHz

This section uses illustrative examples based on CSMAC WG-3 to demonstrate how its sharing proposal is likely to impact the value of spectrum, and how both the type and extent of sharing impacts the value of spectrum in that arrangement. In addition to the issues with geographic sharing illustrated in the WG-1 analysis, above, the bands analyzed by WG-3 introduce *temporal sharing*.

Background. WG-3 was tasked with evaluating the potential for commercial access to the entire 1755-1850 MHz band, but focusing particularly on the lowest 25 MHz at 1755-1850 MHz.[43] This work primarily involved evaluating the potential for interference with the DOD satellite control systems (SATOPS) and electronic warfare deployments that are dispersed through the 1755-1850 MHz band. First, WG-3 found that LTE base stations can coexist with electronic warfare (EW) systems, such as training missions and tests that involved 1755-1850 MHz spectrum. EW operations include the research and development, testing, and training with systems that are meant to defend against electronic attacks in the 1755-1850 MHz band. DOD needs the ability to test and train with devices that operate in the band. For this type of sharing to work, however, there needs to be a framework in place for coordinated temporal sharing around certain DOD training facilities.[44]

WG-3 found that there is potential for interference is from earth stations for SATOPS into commercial receivers on mobile wireless cell sites that are in the vicinity of those earth stations.[45] A number of potential mitigation techniques were also identified for this band. These mitigation techniques ranged from simple solutions, such as optimizing cell tower antenna configurations and building landscape barriers between the LTE base stations and SATOPS, to complex solutions such as dynamic spectrum access (DSA), as well as time and frequency sharing. Alternative solutions included base station filters that can be installed in commercial base

43 Accessing this lowest 25 MHz has been identified as a priority by industry, because it could be used as an extension to the existing AWS-1 allocation. *See,* CSMAC, Working Group 3 (WG 3) Report on 1755-1850 MHz Satellite Control and Electronic Warfare (herein "WG-3 Report"), released July 2013, page 2.

44 *See*, WG-3 Report, pages 9 and 10.

45 They also examined the potential for LTE transmissions to interrupt satellite operations, but found that risk minimal. *See,* WG-3 Report, pages 7 and 8.

stations in the vicinity of satellite earth stations to mitigate the interference. To the extent that harmful interference remains, additional options are to set up geographic zones in which commercial service is either excluded or interruptible, depending on the arc of the satellite.[46]

In its recommendations, WG-3 made it clear that any strategies for sharing in the band must be sufficiently flexible to allow federal spectrum needs to vary over time. It will be some time before SATOPS could transition from the band and, in that time, the need for specific earth stations to communicate with a satellite are likely to change. Moreover, the EW operations at 1850 MHz are particularly valuable for DOD operations, and it is unlikely to vacate the spectrum in the foreseeable future.

1. Electronic warfare

The extent to which EW operations would affect the value of the spectrum is likely to depend on where and when these missions are being carried out and how often the spectrum is being used. Temporary, localized EW operations may require that LTE operations cease in the area for a specific time, and duration. Provided that these operations are limited to DOD facilities, and anticipated well in advance, the likely impact on value would not be substantial. On the one hand, if commercial operators and DOD could negotiate on a time that was acceptable to both parties—for instance, at off-peak overnight hours—the impact on value could be low. On the other hand, if commercial operators do not have warning prior to an interruption, the economic value of the spectrum will decrease. Since CSMAC's WG-3 did not release the specific locations of these training missions, we cannot estimate the specific impact to each facility.

2. SATOPS

WG-3 identifies 23 satellite tracking stations within the 50 United States.[47] WG-3 concludes that when a satellite spacecraft is communicating with a satellite earth station, there would be harmful interference to LTE base stations within the vicinity of the SATOPS facilities.[48]

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46 *See,* WG-3 Report, pages 135 – 152, and 176 – 189.

47 The WG-3 Report identifies 28 satellite tracking stations, but 5 are outside of the 50 United States. The excluded sites are in England, Diego Garcia, Greenland and Guam. Although Guam is a U.S. territory, it does not have excess demand for spectrum and is assumed to not be worth the costs of sharing spectrum.

48 *See,* WG-3 Report, sections 4.2.3 and 4.2.4.

Depending on the orbit of a satellite, the duration of interference from a single pass is typically around 10 to 15 minutes and typically uses 2-4 MHz.[49] However, a single SATOPS usually communicates with multiple spacecraft several times a day and on multiple channels.[50] Table 8 shows the cumulative radiation time by SATOPS and spectrum use over a given year. These results suggest that LTE operations would be limited to some extent in areas for some amount of time. However, the specific interference is conditional on a variety of factors, including the orbit of the satellite, configuration of the SATOPS and LTE base stations, and the terrain.

[49] *See,* WG-3 Report, Figures 4.2.2-2 and 4.2.2-4.

[50] *See,* WG-3 Report, Table 4.2.1-3, Figures 4.2.1-5, 4.2.2-2 and 4.2.2-4.

Table 8. Summary of SATOPS Spectrum Use, 1755-1850 MHz

SATOP Locations	CMA	2010 Population (Count)	Radiation Time (Percent)	Instantaneous Spectrum Use (MHz)	Channel Excluded (MHz)
Annapolis, Maryland	14	2,662,691	4%	2	5
Buckley AFB, Colorado	19	2,733,780	18%	2	5
Blossom Point, Maryland	8	4,814,094	45%	5	5
Cape GA, CCAFB, Florida	137	543,376	46%	2	5
Camp Parks, California	7	4,335,391	0%**	0	0
Colorado Tracking Station, Schriever AFB, Colorado	117	645,613	30%	4	5
Eastern Vehicle Checkout Facility, Cape Canaveral AFS, Florida (Launch support only)	137	543,376	1%	4	5
Fairbanks (NOAA), Alaska	315	145,928	11%	2	5
Ft Bragg, NC	149	319,431	2%	1	5
Fort Belvoir, Virginia	8	4,814,094	20%	4	5
Ft Hood, TX	160	385,623	2%	1	5
Huntington Beach , CA	2	17,053,688	2%	1	5
Hawaii Tracking Station, Kaena Point, Oahu, Hawaii	50	953,207	70%	5	5
Joint Base Lewis-McChord, WA	82	795,225	2%	1	5
Kirtland AFB, New Mexico	86	794,125	1%	2	5
JIATF-S, Key West, FL	370	73,090	2%	1	5
Laguna Peak, California (Navy)	73	823,318	9%	3	5
Monterey, California	126	415,057	4%	2	5
New Hampshire Tracking Station, New Boston AFS, New Hampshire	133	400,721	60%	6	10
Prospect Harbor, Maine (Navy)	466	87,274	3%	3	5
Patuxent River NAS, MD	468	542,006	2%	1	5
Sacramento, CA	35	1,968,069	2%	1	5
Vandenberg Tracking Station, Vandenberg AFB, California	124	423,895	65%	6	10

Notes and Sources:
The Brattle Group Analysis and CSMAC Working Group 3 Final Report (pages 14 - 16).
Note: Excludes SATOP sites in England, Diego Garcia, Greenland and Guam.
** Camp Parks, California is not currently in operation.

To illustrate the forgone economic value from SATOPS operations, we examine several scenarios for sharing between SATOPS and commercial LTE in the entire 1755-1850 MHz band. First, we analyze the impact of excluding all LTE operations in the vicinity of these 23 domestic satellite tracking stations.[51] Next, we estimate the impact on commercial value of allowing LTE operations in the exclusion zones that can be interrupted, either unpredictably or predictably, by the intermittent satellite tracking operations. Depending on the satellites being tracked by each

[51] WG-3 does not conclude what size any exclusion zone would have to be. For the purpose of our illustrative examples, we assumed SATOPS would impact LTE operations in the CMA of the facility.

station, such operations vary in how much spectrum they use and how often they use it. Unless a system is put in place for dynamic spectrum sharing, even if a satellite only uses 2 MHz, the entire affected LTE channel would have to cease operations in that time. As a final step, we consider the value of implementing a DSA system, in which LTE operations can reassign handsets depending on spectrum availability.

a. Scenario 1: SATOPS exclusive use

Based on our analysis, the area surrounding each of the 23 SATOPS facilities represents approximately 41 million people, or 13% of the U.S. population.[52] Similar to WG-1, the value of the spectrum in the areas around these facilities is 30% higher than the national average spectrum value, implying that the excluded area represents 17% of the value of a nationwide spectrum band.[53] In particular, the high value locations include several of the sites in California and Maryland. Excluding the entire 95 MHz of spectrum from commercial use in these areas would preclude approximately 3.9 billion MHz-pops. Factoring both the reduced scope (17%) and the loss in value due to the nationwide premium, the shared band would be 21% less valuable than if it were licensed as exclusive, commercial spectrum. See Table 9 below.

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52 *See,* WG-3 Report, pages 9 and 10. For our analysis, we assume the area in the CMA surrounding the facility is excluded.

53 13% x (1 + 30%) = 17%.

Table 9. Illustrative Example of 1755-1780 MHz Spectrum Value with Exclusion Zones

		Effect on Value
	No Exclusions	
[1]	Population	312,400,577
[2]	MHz-Pop	29,678,054,815
[3]	Value including Nationwide Premium	$29,678,054,815
	Loss from Exclusions	
[4]	Excluded Population	40,915,602
[5]	MHz-Pop	3,886,982,190
[6]	Premium for Relative Value of Locations	30%
[7]	Total Value Lost from Excluded Population	$5,052,012,956
[8]	% Total Value Lost from Excluded Population	17%
[9]	Additional Loss of Nationwide Premium	$1,172,668,660
[10]	Total Value Lost	$6,224,681,616
[11]	% Total Value Lost	21%

Notes and Sources:
The Brattle Group Analysis.
[1]: Total US population, from 2010 Census data, by county.
[2]: [1] x 95 MHz of spectrum.
[3]: [2] x estimated national average $/MHz-Pop ($1.00).
[4]: 2010 population of estimated CMAs covered by excluded zones in CSMAC Working Group 3 Final Report, pages 14 - 16.
[5]: [4] x 95 MHz of spectrum.
[6]: Relative value of excluded population to national average. Based on CMA licenses in Auctions 66 and 73.
[7]: [5] x (1 + [6]) x estimated national average $/MHz-Pop ($1.00).
[8]: [7] / [3].
[9]: ([3] - [7]) x price x (1 - (1 / (1 + nationwide premium))), assuming an average price of $1.00 and a nationwide premium of 5%.
[10]: [7] + [9].
[11]: [10] / [3].

b. Scenarios 2 and 3: Temporal sharing

Given the relatively low radiation time and instantaneous spectrum use of some of these SATOPS facilities, LTE operations may be feasible on an interruptible basis in their vicinity.[54] The key determinant of the impact of these disruptions on the commercial value of using these frequencies is whether or not the commercial users have any warning about when the spectrum will be preempted. WG-3 expresses concern about security issues related to sharing operational schedules of classified operations, suggesting it is not possible to coordinate.[55] So long as the information is not made public it seems plausible that wireless network operators with proper security procedures could use the information to plan network operations without compromising national security. Nevertheless, as this is an unresolved question, we model the impacts of temporal sharing on a predictable and unpredictable basis.

Based on the annual radiation time and simultaneous spectrum use for each SATOPS, the interrupted service represents the equivalent of 32 million MHz-pops over a year, or 0.11% of the spectrum.[56] Due to the nature of the SATOPS sites with the highest use, the relative value weight of the spectrum used would be 80% higher than the average value of nationwide spectrum. So long as the interruptions are predictable and do not represent a substantial portion of the band, there are two negative impacts on spectrum value. These are outlined in Table 10. The economic value is lost due to the reduced scope of services. This results in a 0.19% reduction in value. Given that so little of the spectrum is being used, such an exclusion is unlikely to effect the premium for nationwide spectrum.

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54 According to the WG-3 Report, "at any given moment, about 95% of the spectrum in the 1755-1850 MHz band will be free from SATOPS signal power, thus LTE base stations could theoretically schedule operations to minimize the impact of SATOPS interference." *See*, WG-3 Report, page 147.

55 *See*, WG-3 Report, page 136.

56 Radiation time x interrupted MHz x interrupted pops. With current LTE technology, SATOPS would interrupt operations for an entire LTE channel, so the interrupted MHz is the total channel size. We assume each channel is 5 MHz. On 23 July 2013, the FCC proposed uplink blocks of 5 MHz for 1755-1780 MHz in its Notice of Proposed Rulemaking and Order on Reconsideration for the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands (GN Docket 13-185), paragraph 47.

Table 10. Illustrative Example of 1755-1780 MHz Spectrum Value with Predictable Sharing

		Effect on Value
	No Exclusions	
[1]	Population	312,400,577
[2]	MHz-Pop	29,678,054,815
[3]	Value including Nationwide Premium	$29,678,054,815
	Loss from Exclusions	
[4]	Excluded Equivalent MHz-Pops	32,064,360
[5]	Premium for Relative Value of Locations	80%
[6]	Total Value Lost from Excluded Population	$57,816,671
[7]	% Total Value Lost from Excluded Population	0.19%

Notes and Sources:
The Brattle Group Analysis.
[1]: Total US population, from 2010 Census data, by county.
[2]: [1] x 95 MHz of spectrum.
[3]: [2] x estimated national average $/MHz-Pop ($1.00).
[4]: CSMAC Working Group 3 Final Report, pages 14 - 16. Excluded MHz-Pops calculated as population of excluded CMA, % of radiation time, and the MHz of the channel that would be excluded during radiation time.
[5]: Relative value of excluded population to national average. Based on CMA licenses in Auctions 66 and 73. The large value is driven primarily by the locations in Blossom Point, MD and Fort Belvoir, VA, which are within the Washington, DC CMA.
[6]: [4] x (1 + [5]) x estimated national average $/MHz-Pop ($1.00).
[7]: [6] / [3].

An alternative scenario occurs, however, if the interruptions are unpredictable. In this case, a carrier would likely have to change its business plan to account for the lower quality services due to such interruptions. In the extreme, if there is no predictability about when the interruptions will occur, the geographic areas bands with interruptions will be essentially valueless, because the quality of service will be severely limited. Similar to the analysis in Scenario 1 as reported in Table 9, above, this could amount to essentially a 21% discount to the spectrum value.

c. Scenario 4: Frequency sharing

As the analysis of value presented above indicates, the ability to coordinate temporal sharing will impact the value of the spectrum. Much of this reduction in value is due to the entire loss of LTE service during an interruption. As shown in Table 8 above, however, SATOPS occupy a relatively small amount of spectrum. While current LTE systems cannot schedule operations to use only select frequencies within a channel, WG-3 concluded that future LTE systems could have this capability.[57] If it were possible for LTE base stations to schedule which frequencies it used at specific time intervals, it may be possible to continue service with lower capacity, rather than ceasing operations on a channel altogether.

There are several economic factors to consider in this case. First, assuming that the only frequencies lost are those that are actually being used by the SATOPS when they are communicating with spacecraft, the specific frequencies interrupted would total the equivalent of a little over 24 million MHz-pop. See Table 11. Second, since commercial carriers could continue operations, they would not be subject to the loss in nationwide service premium or degradation of service. Developing these technologies, however, will be costly. WG-3 estimates that the total cost would be "low to moderate" for LTE operators to implement at each SATOPS facility.[58] For the purposes of our analysis, we assume that the cost is roughly $1 million per SATOPS facility, or $23 million for all 23 SATOPS within the 50 states. As illustrated in Table 11, compared to the alternative of excluding this spectrum entirely, this amounts to a total savings of approximately $6.2 billion.

57 *See*, WG-3 Report, page 147.

58 *See*, WG-3 Report pages 181 and 184. According to the WG-3 Report, low cost solutions are less than $1 million per facility and moderate cost solutions are $1 - $10 million per facility.

Table 11. Illustrative Example of 1755-1780 MHz Frequency Sharing

		Effect on Value
	No Exclusions	
[1]	Population	312,400,577
[2]	MHz-Pop	29,678,054,815
[3]	Value including Nationwide Premium	$29,678,054,815
	Loss from Exclusions	
[4]	Total Value Lost, excluding zones	$6,224,681,616
[5]	% Total Value Lost, excluding zones	21%
	Loss Using DSA	
[6]	Upfront Investment	$23,000,000
[7]	Excluded MHz-Pops	24,336,281
[8]	Premium for Relative Value of Locations	102%
[9]	Total Value Lost	$72,213,557
[10]	% Total Value Lost	0.2%
	Savings from Using DSA	
[11]	Savings from Using DSA versus excluding zones	$6,152,468,059
[12]	Savings from DSA versus excluding zones as % of Initial Value	21%

Notes and Sources:
The Brattle Group Analysis.
[1]: Total US population, from 2010 Census data, by county.
[2]: [1] x 95 MHz of spectrum.
[3]: [2] x estimated national average $/MHz-Pop ($1.00).
[4]: See Table 9, [10].
[5]: [4] / [3].
[6]: $1 million x 23 sites.
[7]: CSMAC Working Group 3 Final Report, pages 14 - 16. Excluded MHz-Pops calculated as population of excluded CMA, % of radiation time, and the MHz that would be excluded during radiation time.
[8]: Relative value of excluded population to national average. Based on CMA licenses in Auctions 66 and 73. The large value is driven primarily by the locations in Blossom Point, MD and Fort Belvoir, VA, which are within the Washington, DC CMA.
[9]: [6] + [7] x (1 + [8]) x estimated national average $/MHz-Pop ($1.00).
[10]: [9] / [3].
[11]: [4] - [9].
[12]: [11] / [3].

VII. Facilitating Sharing: Incentivizing Federal Users

It is widely accepted that until Federal users internalize the costs associated with their spectrum use, Federal users have no incentive for using spectrum more efficiently or maximizing spectrum's total social value. Quantifying that foregone value along the lines described above is one way for policymakers to weigh the tradeoffs of conflicting demands and make efficiency enhancing choices about spectrum allocations and assignments, including when spectrum bands should be shared among different classes of users. But knowledge of the right solution is not always sufficient to affect good policy. There remain at least two long term challenges for efficient spectrum sharing.

First, just as commercial users' spectrum demands evolve, government spectrum users' needs are likely to vary over time. As constraints on spectrum get tighter, spectrum will be more heavily used—both temporally and between frequencies. This is the impetus for spectrum sharing. For it to work, however, policymakers need a mechanism for government users to adjust their spectrum usage—and even assignments—according to current needs and cost-effectiveness. Rather than holding spectrum assignments for some future objective or utilizing more spectrum in lieu of potentially more spectrum efficient alternatives, agencies should have a reason to relinquish assignments they are no longer using, or adjust usage to increase the overall efficiency of spectrum, including through increased sharing. An important component of this, however, is that federal users must be assured that they will be able to acquire spectrum assignments when they have a justifiable need. Otherwise, they will still not have an incentive to relinquish spectrum they are not using.

Second, to weigh the true costs and benefits of a wireless communication service, government users need a way to internalize the cost of the spectrum they use. Spectrum is a highly valued, scarce resource. However, once they receive an assignment, federal users do not incur costs to holding on to the asset. This valuable asset is essentially free to them. Federal users typically incur costs associated with utilizing many other valuable assets. For instance, the Government Services Administration charges federal users rent for office space. DOD pays for artillery and machinery. If federal users paid for its use, they would internalize the cost associated with holding spectrum assignments that prevent other productive uses of the frequencies. Recognizing the costs of spectrum would incentivize federal users to adjust their usage to reduce costs. For instance, they may choose to adjust the timing of their spectrum related missions, invest in higher quality filters to limit their spectrum needs, lease capacity from commercial carriers rather than deploy their own services, or more readily accommodate sharing with other users.

Such an approach is consistent with general Presidential directives and Office of Management and Budget (OMB) guidance. A Presidential memorandum released in June 2013 called for an evaluation of spectrum efficiency in procurements and market-based incentives for the efficient use of federal spectrum.[59] The 2013 OMB guidance instructs federal agencies to consider the economic value of spectrum in weighing alternative proposals for deploying spectrum based services.[60] This guidance is intended to ensure "proper stewardship of the spectrum resource."[61] However, government spectrum users still have no consistent basis or incentive to quantify the economic value of spectrum. Federal users need an incentive to adjust their spectrum usage to their need, either in real time, or over time.

Several critical stakeholders have already endorsed a fee based approach.[62] FCC Commissioner Rosenworcel voiced similar sentiments in late 2012.[63] Other countries, notably the UK, have

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59 *See,* Presidential Memorandum, 2013, sections 4 and 6.

60 *See*, Office of Management and Budget, Preparation, Submission, and Execution of the Budget, Circular No. A-11, July 2013, section 31.12, available at: http://www.whitehouse.gov/omb/circulars_a11_current_year_a11_toc (last visited 11 Aug. 2013). According to this guidance:

> The value of radio spectrum required for telecommunications, radars, and related systems should be considered, to the extent practical, in economic analyses of alternative systems/solutions. In some cases, greater investments in systems could enhance Federal spectrum efficiency (e.g., purchase of more expensive radios that use less bandwidth); in other cases, the desired service could be met through other forms of supply (e.g., private wireless services or use of land lines). Therefore, to identify solutions that have the highest net benefits, agencies should consider greater investment to increase spectrum efficiency along with cost minimizing strategies. To this end, section 6411 of the Middle Class Tax Relief and Job Creation Act directed that A–11 be updated with sections (a) and (c). Subsection (b) provides a methodology for determining a baseline to evaluate improvements in spectrum efficiency.

61 *Ibid.*

62 *See,* GAO*,* Federal Government's Use of Spectrum and Preliminary Information on Spectrum Sharing, Testimony Before the Subcommittee on Communications and Technology, Committee on Energy and Commerce, House of Representatives, GAO-12-1018T, 13 September 2012.

63 *See*, Remarks of Commissioner Jessica Rosenworcel at Silicon Flatirons: The Next Ten Years of Spectrum Policy, 13 November 2012.

adopted significant fees for spectrum usage.[64] While there are limitations to a fee-based approach,[65] it would require government users to incur some cost for spectrum usage. Furthermore, accurately set fees would make the costs of federal spectrum usage more transparent. By imposing a spectrum based fee, the cost of spectrum based services for federal users will reflect the use of this scarce resource. The question is: *what should the fee be tied to?*

Consistent with the principle that government spectrum users should consider the forgone economic value of spectrum deployed for their services, we suggest that a federal user fee should be based on the commercial value of spectrum. It may be difficult to calculate the precise economic value of a band of spectrum to a federal user, but this should generally be equivalent to the economic value of the spectrum used—either when shared or used exclusively. While the theoretical economic value of a band of spectrum is difficult to determine, the commercial price of spectrum realized at auction or in secondary trades is one observed estimate of this value. By tying the fee for federal spectrum to spectrum's commercial price, federal users would be incurring the foregone economic value or opportunity cost of the spectrum in deploying these federal services. A fee based on commercial spectrum value would require that federal users at least acknowledge the opportunity cost of the spectrum and defend their use based on this cost.

Calculating the fee would be a two-step process. In the first step, commercially attractive swaths of spectrum currently occupied by federal users would be identified and valued. This may be a 50 MHz or 100 MHz band, the exact size depending on several factors including the currently preferred size of commercial deployments. The commercial value of the band, if it were not shared with federal users, can be calculated using standard spectrum valuation techniques.[66] The lump sum value of the spectrum could be translated into an annual payment through the application of the appropriate discount rate. This value represents the opportunity cost of the band remaining exclusively under federal control.

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64 *See*, for example, Ofcom, "Annual License Fees for 900 MHz and 1800 MHz Spectrum Consultation," 10 October 2013. Available at: http://stakeholders.ofcom.org.uk/consultations/900-1800-mhz-fees/?utm_source=updates&utm_medium=email&utm_campaign=alf-consultation (last visited 22 December 2013).

65 Since agencies are still dependent on Congress to set its budget, any reduced costs would essentially mean a reduced budget from Congress, rather than a reallocation of resources to other important missions of that agency.

66 *See*, Bazelon & McHenry (2013).

The second step of the fee calculation would then be to allocate the value of the band to the individual federal users. This allocation exercise would consider the relative value of all of the users in the band. Agencies that thought they were allocated too large a share of the band's costs would be well incentivized to produce analysis correcting the record. Note that under this scheme, if a federal user chose to stop using a specific band of spectrum, the opportunity cost associated with that band (from step one) would not change and that cost would now be allocated to a smaller group of users. Such an approach would also incentivize spectrum sharing because introducing commercial users in a band would reduce the share of opportunity costs that would need to be covered by the federal users.

This process can be illustrated with a hypothetical example. Suppose a 100 MHz swath of spectrum is allocated to federal users. Further assume the commercial value of this band of spectrum is $1/MHz-pop, suggesting the total commercial value of the band is $31.2 billion.[67] Using a 10% discount rate, the annual cost of using this spectrum would be $3.1 billion.[68] Suppose there are 10 federal agencies that have national assignments of 10 MHz each. One allocation of the fees among the federal users would be to allocate one-tenth, or an annual fee of $310 million, to each agency. If one or more of the federal agencies believed that the value of their spectrum use was less than one-tenth of the value of all federal users in the band, then that agency would be well incentivized to provide supporting evidence of the relative value of the various federal users in the band. Suppose, purely hypothetically, that one of the 10 federal users was the Forest Service and the other nine were law enforcement agencies. In such a case, the Forest Service might submit analysis suggesting that its use is relatively less valuable than law enforcement and, therefore, it should be assigned less than one-tenth of costs of using the band. Such incentives would lead to the expectation that the fees would accurately reflect the relative value of federal users within the band.

The incentive benefits of such a fee would motivate efficient spectrum sharing. If the federal users were to share the band with commercial users, a share of the value of the band would then be paid by commercial users, rather than included in the spectrum fees. For example, if commercial use of the spectrum created $10 billion in value, then $10 billion would be deducted from the total value of the band in calculating the federal fees. In that case, the total value

67 $1/MHz-pop x 312 million pops x 100 MHz.

68 $3.1 billion per year discounted at 10% per year in perpetuity has a present value of $31 billion.

allocated to federal use would drop to $21 billion and the total of the annual fee paid by the 10 federal users would now be $210 million. Note that this creates the incentive for federal users to share with commercial users so long as the value foregone to the federal users is less than the value created by the commercial users.

No federal spectrum user fee scheme will ever create perfect incentives for federal users to use their spectrum assignments efficiently. Beyond the usual principal agent issues that arise with public sector provision of goods and services, the budgetary incentives will never reflect underlying valuations. Congress cannot credibly commit to letting a federal agency keep the value gained by more efficiently using spectrum because they cannot commit to multiyear budgets for agencies. But the spectrum fee proposed here should create some incentives for efficient spectrum use, if for no other reason than shining a light on the costs of spectrum use by federal users. Additionally, the fee setting process proposed here should generate good, accurate information about the value of federal spectrum use—information policymakers can utilize in more direct spectrum management decisions.

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