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The Economic Basis of Spectrum Value: Pairing AWS-3 with the 1755 MHz Band is More Valuable than Pairing it with Frequencies from the 1690 MHz Band

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INTRODUCTION AND OVERVIEW

Broadband connectivity is becoming increasingly important to modern society—from facilitating economic activity to increasing the effectiveness of government. This connectivity is increasingly being provided over mobile wireless networks. To meet the growing demand for wireless broadband, access to additional radio spectrum frequencies will be essential. Such frequencies, particularly those below 3 GHz that are suitable for mobile communications, are a limited resource. Consequently, access to them is highly valuable.

Ensuring that spectrum rights are distributed efficiently—licensed to the users who can make the most productive use of them—is critical. In an unconstrained market where rights to access spectrum are freely traded, market forces would ensure that spectrum is put to its highest valued uses. In the current system of administratively allocated spectrum rights, market mechanisms cannot provide the incentives or avenues for radio spectrum to move from lower to higher valued uses. Therefore, care must be given in the allocation process to put spectrum to its highest valued uses. Getting this wrong has big costs, most importantly in lost consumer welfare.

This paper will focus on the 20 MHz AWS-3 band and the potential to pair it with either the 1690 MHz[1] or 1755 MHz band. The key question is which lower band pairing will create the most economic value? To answer this question, this paper first discusses the economic underpinnings of spectrum value. Spectrum is not inherently valuable; rather its value is derived from the value of spectrum-based services that can be provided. As a result, bands of spectrum that are more costly to deploy are worth less than bands that are less costly to deploy.

Any cost differences between pairing the AWS-3 band with 20 MHz in the 1755 MHz band versus pairing it with 20 MHz in the 1690 MHz band translate into value differences. This paper identifies three specific cost differences between the 1755 MHz and 1690 MHz bands and estimates their effect on spectrum value. First, increased network infrastructure costs lower future profits, causing the net present value to decline. Second, added costs of devices such as handsets and computer dongles lead to increased customer subsidies, again causing profits and spectrum value to be lower. Third, added risk of using a non-standardized band results in more heavily discounted—that is, lower present value—future expected profits.

The cumulative effects of these cost differences are substantial. The value of the AWS-3 band paired with the 1755 MHz band is approximately $12 billion. (Including the additional 5 MHz at 2175 MHz to 2180 MHz and using the entire 25 MHz of the 1755 MHz band would increase this value by about 25%.) A well structured FCC auction would be expected to realize this value in bids for access to the spectrum. Pairing the AWS-3 band with the 1690 MHz band would reduce expected receipts by $4.7 billion, to $7.3 billion. An asymmetric pairing with 1695 MHz – 1710 MHz would reduce receipts a further $0.9 billion, to $6.4 billion. Accounting

[1] Although the FCC has requested comments on pairing with the spectrum in the 1675 MHz – 1710 MHz band, this paper focuses on the 1690 MHz to 1710 MHz band for the 20 MHz allocation and the 1695 MHz to 1710 MHz band for the 15 MHz allocation. Given the band options between 1675 MHz and 1710 MHz, it would be most optimal—should this option be selected—that the pairing include the 20 MHz of spectrum adjacent to the existing AWS-1 1710 MHz band.

for the exclusion zones associated with the 1695 MHz band, receipts would be reduced by an additional $1.1 billion, to $5.3 billion. Although a significant reduction in value, any of these pairings is preferred to allocating the AWS-3 band as unpaired. In that case, expected auction receipts would be only $3.6 billion.

ECONOMICS OF SPECTRUM VALUE

Why is radio spectrum valuable? Unlike gold, radio spectrum is not inherently valuable. Rather its value derives from its use in producing services. The value today is simply the present value of the future profits that can be earned using the resource. As the profitability of providing spectrum-based services such as wireless broadband increases, for example because demand for those services increases, the value of the spectrum asset also increases. Likewise, if the future stream of profits from providing spectrum based services decreases, for example because the cost of providing those services increases, then the value of the spectrum asset decreases. In fact, different bands of spectrum have different values specifically because the profitability of the services that can be provided with those bands differ.

SPECTRUM VALUE IS DERIVED FROM THE VALUE OF SPECTRUM BASED SERVICES

Spectrum is not a store of value; rather, it is an input into the production of valued services. These spectrum-based services include mobile communications (such as cell phones and mobile broadband), fixed communications (such as broadcasting and wireless data links), and detection applications (such as radar). Provision of such services increases consumer welfare by providing valued services. Typically, consumers benefit more than what they pay for services—in the case of wireless services the excess benefit can be substantial.[2] The derived value of spectrum is based on the value it adds to these services.

For example, to provide mobile phone service, a service provider must first secure rights to use radio spectrum, make capital investments to build a network, and then commit to expenditures to operate, market, and deliver mobile phone service. Building a mobile phone network requires significant capital investments in such things as cell sites (renting or building towers, hanging radios, installing other communication and electrical equipment on site), back-haul capabilities, and network operations centers. To provide service an operator must market its service, operate its network, and provide customer support and billing services. Profit is what remains after revenue from customers is collected and all of the inputs into this process (construction costs, salesperson salaries, etc.) are paid. What a network operator can pay to secure the spectrum rights is determined by these profits. The operator cannot pay more than the value of those profits (or the operator would lose money on the venture). The operator is also unlikely to pay much less than this or a different operator (also able to make profits from

[2] Bazelon, Coleman. "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations." Sponsored by *Consumer Electronics Association*, 2009, p. 21.

deploying and operating a wireless network) would be willing to pay more than the first operator for access to the scarce spectrum rights.

The value of a given band of spectrum 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. For example, because a fixed microwave data link could be replaced with a fiber optic cable if the microwave data link becomes more expensive, the price of data transmission services via fixed microwave link will not rise above the price of those services when provisioned over a fiber optic link. The cost of the alternative limits how profitable the spectrum based service will be and, in turn, how much value is attributable to the spectrum resource.

For services that have no alternative to using spectrum, such as mobile phone service, the value of spectrum is limited by the incremental capital costs of increasing capacity on existing bands of spectrum. As the example above illustrates, capital investments in cell sites are required to use spectrum for mobile phone service. One alternative to investing in a given band of spectrum is to provide the same capacity with less spectrum (or greater capacity can be provided with the same amount of spectrum) by increasing capital investments to make cells smaller and increase the amount of frequency reuse.[3] Note that these capacity-increasing capital expenditures become progressively more expensive.[4] Additional spectrum is only economically viable if the cost is lower than that of expanding the existing capacity of spectrum through increasingly expensive capital investments.

SPECTRUM VALUE IS BASED ON THE ECONOMIC CONCEPT OF RENT

Things that are in relatively fixed supply (or have inelastic supply in the language of economists[5]) garner what economists call economic rent.[6] The iconic example of rent is the value of land; the concept applies equally well to radio spectrum.[7] Rent is payment based on

[3] Another alternative is to upgrade to more spectrum efficient technologies. For a more complete discussion of this tradeoff between spectrum and capital investments, see "Mobile Broadband: The Benefits of Additional Spectrum." FCC Staff Technical Paper, October 2010: pp. 20 – 21. http://www.fcc.gov/Daily_Releases/Daily_Business/2010/db1021/DOC-302324A1.pdf

[4] As the coverage of cell sites get smaller, dividing the cell creates less incremental capacity, but the costs of smaller cells does not decrease nearly as fast and at some point may not decrease at all.

[5] In the current case, spectrum economists refer to the relatively fixed supply as a supply elasticity close to zero. Supply elasticity is measured as the ratio of the percentage change in supply of a resource, given a percentage change in its price. For example, if elasticity is equal to 1 a 10 percent increase in price implies a 10 percent increase in supply. An elasticity that is close to zero is said to be inelastic, since a 10 percent increase in price will result in a near zero percent increase in supply.

[6] Ricardo, David. *On the Principles of Political Economy and Taxation*, Chap. 2 "On Rent". 1821. Library of Economics and Liberty. 26 July 2010. <http://www.econlib.org/library/Ricardo/ricP.html>. See also Jevons, William Stanley. *The Theory of Political Economy*. 1888. Library of Economics and Liberty. 26 July 2010. <http://www.econlib.org/library/YPDBooks/Jevons/jvnPE.html>; Sowell, Thomas, *On Classical Economics*, Yale University Press, 2006: pp. 50 - 54; Blaug, Mark. *Economic theory in retrospect*. Cambridge University Press, 1997: pp. 75 – 84 and 112 – 114.

[7] Like land, the total amount of radio spectrum is fixed. Similar to land, some is under private control and some is publicly owned with public access rights. The discussion herein applies to licensed radio spectrum, analogous to privately owned land. Some analysts argue that spectrum should not be managed

scarcity. Land in Manhattan is scarce in the sense that there is high demand for it and limited supply. Similarly, attractive frequencies for mobile telephony are scarce—there is much demand for them and they are in limited supply. The amount of rent paid for an asset reflects its scarcity, which in turn reflects the added value created by a given asset over its alternative. The concept of economic rent applies equally to the sale of assets as it does to the lease of assets, which is the more common usage of the term "rent."

The value of a spectrum license is captured by economic rent. To understand economic rent, generally it is helpful to differentiate between normal economic returns for a product, and the value added by some capital asset. In a competitive market normal economic returns cover the cost of capital investment (including interest payments and returns to equity holders) and production. This ensures it is worthwhile to stay in the market. Any return above these normal economic returns is economic profit. Economic profit occurs because the product has some added value, based on a scarce resource such as a capital asset, that is not a generic input into production. When economic profits are attributable to a capital asset, the portion of profit derived from using a particular capital asset is referred to as the rent of that asset.

Put differently, the economic rent of an asset is the added value, or net return to investment, of using that asset over the least efficient, or least desirable, alternative asset available. As the quality of assets diminishes incrementally relative to superior assets, the economic rent of the inferior assets also decreases until, in Ricardo's words "the capital last employed pays no rent."[8] Economic rent, therefore, represents the additional value a producer is willing to pay to use the characteristics and quality of an asset.[9] When the capital assets of production are fixed (inelastic), economic rent is the additional profit or value, above normal economic returns, from using a superior asset. For instance, this is the value of the microwave link over the cost of fiber optic cable. Alternatively, this is the value of deploying additional spectrum over the capital costs of increasing capacity by the same amount through cell splitting.

(as much) under a licensed regime, but rather should be unlicensed. This issue of licensed versus unlicensed access to radio spectrum is beyond the scope of the current paper; however, I have addressed it elsewhere. See, Bazelon, Coleman. "Licensed or Unlicensed: The Economic Considerations in Incremental Spectrum Allocations." *IEEE Communications Magazine*, March 2009: pp. 110-116. For a discussion of the difference between property regimes (licensed vs. unlicensed) and access regimes, see, Hazlett, Thomas W., and Coleman Bazelon. "Market Allocation of Radio Spectrum." Prepared for the *International Telecommunications Union Workshop on Market Mechanisms for Spectrum Management*. Geneva, Switzerland, January, 2007.

[8] Ricardo, David. *On the Principles of Political Economy and Taxation*, Chap. 2 "On Rent". 1821. Library of Economics and Liberty. 26 July 2010. <http://www.econlib.org/library/Ricardo/ricP.html>. Chapter 2. Paragraph 9.

[9] This concept is similar to opportunity cost, or the additional value of using an asset for one purpose over the next best alternative. Opportunity cost captures the concept of alternative uses for an asset. For instance, one might ask what is the opportunity cost of using a given set of frequencies for broadcasting versus for mobile broadband. (The answer to that question can be found in Bazelon, Coleman. "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations." Sponsored by *Consumer Electronics Association*, 2009.)

Since economic rent represents what a producer is willing to pay for the privilege of use, it is not theoretically captured by the producer, but extracted by (i.e., paid to) the asset owner.[10] When the producer must pay for the use of such a fixed capital asset, these economic profits are transferred from the user of the asset to the owner of the asset in the form of rental payments (or the equivalent, such as licensing fees.) For example, in the case of farming, there is no economic profit to farming over the long run (because farmers are in elastic supply and more farmers will enter the market if there is economic profit), but there may be to owning farmland.[11]

SPECTRUM VALUE IS THE PRESENT VALUE OF A STREAM OF FUTURE PROFITS

The "owner" of a band of spectrum could either extract the economic profits of using that band year-by-year, say through some sort of leasing arrangement[12] or, as when FCC licenses are auctioned, in a lump sum for the current value of the license rights over some predetermined number of years. To calculate the present value of the economic profits earned from the spectrum over time, the economic concept of net present value (NPV) is employed.

As with any capital investment, the net return of investing in a band of spectrum will be realized over time. The upfront capital investment is expected to result in a stream of net returns (revenue, minus cost), over the lifetime of the asset. The value of the investment and expected stream of profits depends critically on the timing of this stream of returns. The present value of any future payment is equal to the amount you would need to invest today to receive that future return. Given an interest rate of 5 percent, the present value of $105 next year is $100 today. Just as the value of $100 today is greater than the value of anticipating receiving $100 next year, the value of a capital investment project that does not begin to yield a stream of revenue until next year will be lower than a similar project that yields profits immediately. This concept of the time value of money is captured by the NPV.

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. The present value of any investment is equal to the sum of the present value of each annual net return or cash flow (CF), discounted by the rate of return for that year[13]:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+R_t)^t}$$

[10] In the case of farmland, the landlord captures this value in rent. If a tenant is not willing to pay, the landlord can find another who is willing to pay for the added productive value of the specific land.

[11] The owner and user of an asset may be the same entity (or farmer), but the income earned as an owner is distinguished from the income earned as a user.

[12] For example, spectrum lease agreements typically require payments of between 10% and 20% of gross revenues from using the spectrum. Such payments are a proxy for the economic profits earned from using the band of spectrum.

[13] Damodaran, Aswath. *Investment Valuation 2nd Edition*. New York, NY: John Wiley and Sons, 2001.

Investments that have higher levels of risk have higher expected rates of return (R) or, equivalently, higher discount rates. As a result, the NPV of each anticipated cash flow is more heavily discounted today. Consider two equal streams of profit that have different levels of risk, but the same expected cash flow. The less risky investment with a lower interest rate is more valuable today. It is important to note that the riskiness of an investment that leads to a higher discount rate is not simply the uncertainty about expected returns; rather, it is how those returns are correlated to the returns of a well balanced portfolio of investments.[14] If the chance of being above or below the expected value of an investment is unrelated to other investments, then the financial markets will treat the investments as riskless. (This is because the risk can be diversified away.) When evaluating different streams of expected profits from using spectrum, the discount rates used would differ only if one of the investment's returns were more correlated to overall economic performance than the other investment's returns.

IMPLICATIONS FOR SPECTRUM VALUE: DIFFERENCES IN SPECTRUM VALUE ARE BASED ON DIFFERENCES IN SPECTRUM QUALITY

Differences in the value of bands of spectrum are driven by differences in the added value of using them, which broadly reflects differences in the quality of spectrum. The quality of a band of spectrum is determined by at least three factors: the physical characteristics of the spectrum, including frequency wavelengths and potential pairings; the existence of band compatible technology for both infrastructure and devices; and encumbrances to use, such as incumbent users and service restrictions placed on licenses. Each of these factors of quality impact the value of a band by affecting the revenues, costs, and uncertainties of using the spectrum. The relative quality of a spectrum band varies by use (i.e., broadcast vs. wireless services), region (i.e., rural vs. urban) and the availability of technology and infrastructure for specific uses of the band.

*Physical characteristics***.** The wavelength of a frequency is a key determinant of its best uses. Frequencies above about 3 GHz are not currently as conducive to mobile communications. Lower frequencies require less energy to transmit signals over a given distance and are more capable of penetrating walls and buildings. Even for frequencies under 3 GHz, higher frequency spectrum within that range requires more cells and higher power levels vis-à-vis lower frequency spectrum for the same level of coverage, resulting in either higher costs for the same level of service, or lower quality service, less capacity and diminished revenue. The extent to which higher frequencies are less valuable depends on the intended use. Long signal range is more important in rural areas. In urban areas, the high density of users requires more cells, making this issue less relevant.

Given the current state of technology, pairing spectrum also tends to make the spectrum more valuable. For spectrum services that require two-way communications, pairing bands allows them to be used more efficiently by diminishing interference from incompatible adjacent

[14] Technically, this is known as the beta of an investment and measures the covariance of the returns to an investment with the returns to a well balanced portfolio of investments. See, Damodaran, Aswath. *Investment Valuation 2nd Edition*. New York: John Wiley and Sons, 2001.

operations.[15] As discussed in more detail below, this greater efficiency is seen in relative spectrum prices.

Existence of Applicable Technology. The ecosystem of a band of spectrum—both in technology and in users and services—can greatly affect its value. Any new wireless technology requires network equipment and devices. Spectrum users must find suppliers for both. The compatibility of existing infrastructure, hardware and software with the radio frequencies within a band is a critical determinant of its value because research and development is costly, time consuming and risky.[16] Often a more mature band already has equipment available to use the spectrum. This is considerably less costly to use immediately or upgrade. It may also have a more readily accessible user base, potentially increasing expected revenues. A larger amount of bandwidth in a band also tends to create more demand for equipment. Economies of scale and scope decrease the cost and burden of fixed research and development costs for individual users of the band because they can take advantage of conventional hardware and software. Mature bands that are internationally harmonized tend to have larger user bases, and thus, lower costs, and higher certainty of the availability in the latest technology.

Encumbrances. Restrictions on licensed use, the existence of incumbent users, or interfering neighbors decreases the value of spectrum because it potentially restricts revenues, increases costs and raises uncertainties about profit timing. Many bands have incumbent users that must be migrated to different radio frequencies before the spectrum is fully available. Exactly when this will occur adds even more uncertainty to a project. Limited use of a band in the interim may be a possibility, but it will likely diminish revenues. Uncertainty in spectrum availability and profit timing can diminish a band's expected value.

Licensing restrictions may reduce revenues by limiting the capacity or the types of services for a given spectrum band. This can clearly be seen in the television bands where licensees are restricted to broadcasting and cannot repurpose the spectrum themselves. The spectrum allocated to television broadcasting would be worth about $62 billion if completely unencumbered and reallocated to broadband services, but is only worth about $12 billion when used in broadcasting.[17] This difference of $50 billion represents the diminished value of those frequencies as a result of license restrictions, such as not being allowed to lease spectrum for any use except broadcasting.

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[15] See discussions on AWS-3 band interference in "Notice of Proposed Rulemaking in the Matter of Service Rules for Advanced Wireless Services in the 2155-2175 MHz Band." FCC Docket 07-164 adopted September 7, 2007, released September 19, 2007; and in "AWS-3 To AWS-1 Interference Laboratory Test Report." *T-Mobile USA, Inc.,* downloaded August 18, 2010 from <http://fjallfoss.fcc.gov/ecfs/document/view?id=6520035719>. To avoid interference, the FCC could set power restrictions on the single band, which would decrease its capacity, see, "Advanced Wireless Service Interference Tests Results and Analysis." *FCC*, October 10, 2008, downloaded August 18, 2010 from <http://fjallfoss.fcc.gov/edocs_public/attachmatch/DA-08-2245A2.pdf>.

[16] See, Varrall, Geoff. "RF Cost Economics for Handsets." *RTT* white paper, May 2007 <www.rttonline.com/research/RFCostEconomicsForHandsets-study.pdf> for further discussion.

[17] See, Bazelon, Coleman. "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations." Sponsored by *Consumer Electronics Association*, 2009. This valuation assumes no restrictions or encumbrances on the reallocated TV frequencies when they are sold.

Having to tolerate interference from—or to prevent interference into—users in neighboring bands also reduces the usefulness of a band and, consequently, its value. Operating in an environment with interference can require higher power levels or other adjustments that decrease the capacity of a band of spectrum. Less capacity, or otherwise doing less with the same inputs, reduces the value of spectrum.

PAIRING AWS-3 BAND

The FCC's National Broadband Plan (NBP) raised the issue of pairing the AWS-3 band. Specifically, the NBP asked that the National Telecommunications and Information Administration (NTIA) explore the possibility of pairing the AWS-3 band with spectrum in the 1755 MHz – 1850 MHz band. NTIA responded by proposing consideration of the 1675 MHz – 1710 MHz band.[18] Because both of these bands are used by the federal government the issue will be resolved by the FCC working in conjunction with the NTIA and relevant federal agencies.

An NTIA report dated October 2010 recommends reallocating 115 MHz of spectrum currently devoted to Federal agencies to wireless broadband over the next five years. Their proposal included making the 15 MHz of spectrum in the 1695 MHz – 1710 MHz band available for pairing with the AWS-3, subject to exclusion zones covering 12% of the US population.[19] This 15 MHz was the only spectrum below 3 GHz that NTIA made a recommendation on. Although it was up for fast track consideration, NTIA said it was unable to comment on the 1755 MHz – 1780 MHz spectrum at that time.[20] More recently, the NTIA identified the 1755 MHz – 1780 MHz band as the next band they will evaluate for reallocation.[21]

VALUE OF PAIRING

Traditionally, two-way communications, such as mobile phone services, have been provided over paired bands of spectrum. With a paired band, a portion of the frequencies (usually half) are used to transmit from the base station to the mobile device and the remainder of the band is used for mobile to base station transmissions. The two bands in the pair are separated from each other so the up-stream and down-stream transmissions are not adjacent in

[18] "Connected America: The National Broadband Plan." *FCC*: pp. 86 – 87. (Referred to hereafter as "*NBP*.") See also, "Spectrum Policy in the Age of Broadband Issues for Congress." *CRS*, June 21, 2010; FCC Public Notice, DA 10-1035, released June 4, 2010.

[19] The exclusion zones included the major markets of Washington DC, San Francisco, Miami, and substantial portions of Los Angeles. See Table 1. "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." *NTIA,* October 2010. (Referred to hereafter as "*NTIA Report.*") According to the report, "NTIA recommends that 15 megahertz of the 1675-1710 MHz (specifically 1695-1710 MHz) spectrum could be made available for wireless broadband use within five years" (p. v). NTIA reviewed this band as a possible pairing with the 2155-2180 MHz band (p. iv).

[20] See *NTIA Report.*

[21] "NTIA Takes Next Step in 500 MHz Wireless Broadband Initiative, Agency to Conduct a Detailed Analysis of the 1755-1850 MHz Band," available at: http://www.ntia.doc.gov/press/2011/500mhzstatement_02012011.html.

order to prevent interference with each other. Most currently deployed mobile communications systems use symmetrically paired spectrum.

Licensed unpaired spectrum has traditionally been used for broadcasting—the one-way transmission of radio signals.[22] More recently, newer technologies allow for the use of unpaired spectrum for two-way communications. WiMax and future releases of LTE can use unpaired spectrum either for stand alone two-way communications systems or for one-way communications in conjunction with paired bands.[23] In most relevant cases, the performance of unpaired spectrum is not as high as paired spectrum.[24]

The difference in profitability of using paired versus unpaired spectrum is reflected in the value of the two types of spectrum. This was very clearly seen in the 700 MHz auction in 2008.[25] In that auction four bands of very similar 700 MHz spectrum were auctioned. The Lower A and B blocks had 12 MHz of paired spectrum with 6 MHz bands each for uplink and downlink (A block: 698-704/728-734 MHz; B block: 704-710/734-740 MHz). The Upper C block totaled 22 MHz of paired spectrum with 11 MHz bands each for uplink and downlink (Upper C block: 746-757/776-787 MHz). Only one unpaired band, the Lower E block which was 6 MHz (E block: 722-728 MHz) was sold at the same time. The average price of the A, B & C blocks was $1.36/MHz-Pop and the average price of the E Block was $0.74/MHz-Pop, a discount of 46% for the unpaired band.[26] Furthermore, as noted in the National Broadband Plan, pairing the AWS-3 band with another band would likely increase its value.[27]

The difference in value of paired versus unpaired bands has likely changed somewhat in the intervening two years. The existence of technology to use unpaired spectrum for two-way communications—notably WiMax—was known at the time of the 700 MHz auction. In the intervening two years, the technology has become more developed, and a modest revision of

[22] Radar also uses unpaired bands, but radar is not a commercially relevant application and not included in the rest of the analysis. Unlicensed bands, such as those used for WiFi are also unpaired.

[23] "Spectrum Analysis for Future LTE Deployments," Motorola White Paper downloaded on September 12, 2010 from: <http://www.motorola.com/staticfiles/Business/Solutions/Industry%20Solutions/Service%20Providers/Wireless%20Operators/LTE/_Document/Static%20Files/LTE_Spectrum_Analysis_White_Paper_New.pdf>. For a discussion of technology for unpaired spectrum, including WiMAX and LTE, see Ramsay, Maisie. "TD-LTE: A Threat to WiMAX?." *Wireless Week.* July 15, 2010, downloaded January 17, 2011 from <http://www.wirelessweek.com/Articles/2010/07/Networks-TD-LTE-A-Threat-To-WiMAX/>.

[24] "Spectrum Analysis for Future LTE Deployments." *Motorola*, downloaded September 12, 2010 from <http://www.motorola.com/staticfiles/Business/Solutions/Industry%20Solutions/Service%20Providers/Wireless%20Operators/LTE/_Document/Static%20Files/LTE_Spectrum_Analysis_White_Paper_New.pdf>

[25] A discount for unpaired spectrum was also seen in the recent 2.6 GHz auctions in Germany. See slide 12, Dr. Ulrich Stumpf and Dr. Lorenz Nett. "The German auction design – Conclusions for Europe." *European Workshop on Spectrum Auctions* at the Federal Network Agency. October 29, 2010, downloaded January 17, 2011 from <http://www.bundesnetzagentur.de/cae/servlet/contentblob/161682/publicationFile/8987/3_WIKTheGermanAuctionDesign.pdf>.

[26] Bazelon, Coleman. "Too Many Goals: Problems with the 700 MHz Auction." *Information Economics and Policy*, April 8, 2009.

[27] "Connected America: The National Broadband Plan" (NBP) *FCC*: pp. 86 – 87. See also, "Spectrum Policy in the Age of Broadband Issues for Congress." *CRS*, June 21, 2010; FCC Public Notice, DA 10-1035, released June 4, 2010.

expectations from early 2008 of using unpaired spectrum for two-way communications may be in order. This is illustrated by Qualcomm's recent sale of its portion of the E Block and the entire Lower 700 MHz Band D Block (also an unpaired 6 MHz band) to AT&T. The sale represented an increase in value over the 700 MHz E Block of 5.5%.[28] However, given that the value of the 700 MHz paired spectrum has declined by 5%[29] over the same time period the implied discount for unpaired spectrum compared to paired spectrum would be 40%.[30] I will use this updated discount throughout the remainder of this analysis.

TWO POTENTIAL BANDS

The two potential bands to pair with the AWS-3 band are the 1690 MHz band and the 1755 MHz band. The NBP proposed that NTIA consider benefits of pairing the AWS-3 with the 1755 MHz – 1850 MHz band. NTIA decided to assess 1675 MHz – 1710 MHz band as a possible pairing. In turn, FCC requested comments on a 1675 MHz – 1710 MHz pairing.[31] The spectrum between the two bands, at 1710 MHz – 1755 MHz, is already allocated as the AWS-1 band.

1755 MHz – 1780 MHz band

This band is currently allocated by the federal government and used for fixed microwave communication and video surveillance systems that had been migrated from the 1710 MHz –

[28] In December 2010, AT&T agreed to acquire 6 MHz of Qualcomm's nationwide D Block spectrum and another 6 MHz of E Block spectrum in 5 metropolitan markets for $1.925 billion. (See "AT&T Agrees to Acquire Wireless Spectrum from Qualcomm." AT&T press release. December 20, 2010.) Qualcomm's E Block licenses, which was comprised of 6 MHz of unpaired spectrum in 5 metropolitan markets, represented 44% of the nationwide E Block value in Auction 73. Assuming that the value of the 6 MHz of nationwide D Block spectrum that AT&T acquired is equal to the value of the E Block nationwide, this deal represents 144% of the value of spectrum licensed in the E Block Auction 73 (i.e., 100% of the 6 MHz D block nationwide, plus 44% of the value for 6 MHz of E block in 5 metropolitan areas). At the time of the Qualcomm deal, the E Block alone would be worth $1.337 billion ($1.925billion/1.44). This represents a 5.5% increase in value over the $1.267 billion realized during Auction 73. (See Auction 73 results downloaded from FCC Auctions at http://wireless.fcc.gov/auctions).

[29] SpecEx Spectrum Index from Spectrum Bridge® values of 300 on March 18, 2008 and 285 on December 20, 2010 retrieved January and April from <http://spectrumbridge.com/products-services/specex/index.aspx>. SpecEx Spectrum Index tracks changes in spectrum value reasonably well. For instance, the change in SpecEx Index values closely tracked the change in AWS spectrum value based on NextWave's AWS spectrum sale to T-Mobile in July 2008. The NextWave sale reflected a 91% increase in AWS spectrum value, whereas, the SpecEx Index in the same period indicated an 86% increase in spectrum value. See Auction 66 results from <www.fcc.gov/auctions> and NextWave Wireless Inc. 8-K filed July 23, 2008 for details.

[30] The value of unpaired spectrum increased by 5.5% from $0.74 MHz-Pop to $0.78 MHz-Pop. Over the same period, the value of paired 700 MHz spectrum decreased by 5% to $1.29 MHz-Pop. Unpaired spectrum is now 60% of the value of paired spectrum, representing a 40% discount for unpaired (over paired) spectrum.

[31] FCC Public Notice, DA 10-1035, released June 4, 2010.

1755 MHz to clear AWS-1 band. The band also holds military mobile communication equipment, as well as satellite uplinks for telemetry, tracking and control of satellites.[32]

This spectrum is already internationally harmonized for commercial mobile use. In fact, some countries already allocate spectrum 1710 MHz – 1780 MHz to such uses.[33] As a result, there are currently devices available that will work with this band, which create international "synergies" and reduce uncertainty associated with developing handsets and software.[34] Additionally, the duplex spacing (i.e., the spectrum "distance" between the top of the upstream and downstream links) would be identical to the AWS-1 spectrum. This would also potentially cut down on the cost of developing compatible devices.[35] This spectrum is well suited to commercial mobile services, and was recognized by the NBP as a good candidate for pairing with the AWS-3 band.

Although only 20 MHz of the 25 MHz in the 1755 MHz – 1780 MHz band is needed to pair with the AWS-3 band, the 5 MHz just above the AWS-3 band at 2175 MHz to 2180 MHz could be added to the allocation (for an addition of 10 MHz in total) to make a new allocation with a total of 50 MHz of paired spectrum. Such an allocation would be 25% larger than the 40 MHz paired allocation considered in this analysis. Similarly, its value would be approximately 25% greater.

1690 MHz – 1710 MHz band[36]

The 1690 MHz – 1710 MHz block is allocated to the federal government and currently used primarily by federal agencies for weather, research and defense.[37] Agencies using this spectrum include the National Oceanic and Atmospheric Administration (NOAA) and other research groups that transmit weather related information through NOAA satellites. These groups use the band as the downlink from weather satellites and weather balloons.[38]

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[32] See "Federal Spectrum Use Summary", *NTIA*, June 21, 2010, downloaded on September 12, 2010 from <http://www.ntia.doc.gov/osmhome/spectrumreform/Spectrum%20Use%20Summary%20Master-06%2021%2010.pdf>.

[33] See *NBP*, p.86. See also, Table 1 of Varrall, Geoff. "RF Cost Economics for Handsets." *RTT* white paper, May 2007 <www.rttonline.com/research/RFCostEconomicsForHandsets-study.pdf>. See also, "In the Matter of Office of Engineering and Technology Requests Information on Use of 1675 – 1710 MHz Band." *Comments of CTIA – The Wireless Association* before the FCC, ET Docket No. 10-123, June 28, 2010.

[34] See *NBP*, p. 86.

[35] See, Varrall, Geoff. "RF Cost Economics for Handsets." *RTT* white paper, May 2007, available at <www.rttonline.com/research/RFCostEconomicsForHandsets-study.pdf> for discussion of how standard spectrum allocations lower the cost of developing handsets.

[36] This paper assesses the value of the 20 MHz of spectrum from 1690 MHz to 1710 MHz. Any other 20 MHz block of the frequencies between 1675 MHz and 1710 MHz would have lower values than those estimated here.

[37] FCC Public Notice, DA 10-1035, released June 4, 2010. For further detail see, "Federal Spectrum Use Summary, 30 MHz – 3000 GHz." *NTIA Office of Spectrum Management*, June 21, 2010.

[38] *Ibid*.

The 1690 MHz – 1710 MHz is not internationally harmonized for commercial wireless use.[39] In addition, the duplex spacing created by potentially pairing with AWS-3—465 MHz—is wider than any other major allocation used and does not conform with the duplex spacing of the adjacent AWS-1 band. This would require developing new receivers and extending existing radios to accommodate a wider band of spectrum. An asymmetric pairing of the 20 MHz of the AWS-3 band with the 15 MHz of the 1695 MHz to 1710 MHz band proposed by NTIA will be worth less than a symmetric pairing because it has less capacity. This issue will be discussed further below.

Sources of Cost Differences between the Two Bands

Regardless of the pairing, there are costs associated with building infrastructure to use the AWS-3 band for wireless services. Either pairing would require new base station transmission equipment for the new spectrum including antennas and tower-top amplifiers to reach the upper end of the 2175 MHz spectrum. There are, however, several cost differences that could materially affect the value of the spectrum.

Equipment Harmonization. Acquiring equipment for the non-harmonized 1690 MHz band will likely take additional time and require higher consumer costs. Economies of scale already exist for a band that is internationally harmonized for commercial use, such as the 1755 MHz band. Specifically, there are manufacturers that already produce compatible equipment for both the network and for consumers for the 1755 MHz band. By contrast, the 1690 MHz band will likely require the development of new equipment. Many manufacturers are reluctant to develop equipment for a non-harmonized band because the demand is inherently limited. It is likely that equipment will be both more expensive, take longer to develop, and have fewer features.

Band Clearing Costs. The costs of clearing a band can affect its value. If operators must incur additional costs to clear a band of spectrum—either through direct payments or increased regulatory activity—profits and spectrum value are reduced commensurately. Costs from delay of clearing incumbents can also reduce spectrum value if it delays the timing of realizing profits. This cost from delay can still be a concern even if the relocation costs are paid from a government fund. To the extent clearing the 1690 MHz band is more expensive, takes longer, or is more uncertain than clearing the 1755 MHz band, then, other things being equal, the present value of profits derived from that band would be lower.

Spectrum Sharing/Exclusion Zones. When bands of spectrum have incumbent users that are prohibitively expensive to relocate, portions of the band may be put to multiple uses through the various sharing techniques. In such cases, spectrum sharing strategies can have the advantage of making otherwise unavailable spectrum usable, but that value is diminished compared to unencumbered spectrum. One particularly blunt spectrum sharing strategy is to designate exclusion zones around incumbent users that are not going to be reallocated. This is the

[39] "In the Matter of Office of Engineering and Technology Requests Information on Use of 1675 – 1710 MHz Band." *Comments of CTIA – The Wireless Association* before the FCC, ET Docket No. 10-123, June 28, 2010.

approach proposed by the NTIA with respect to the 1695 MHz – 1710 MHz band.[40] The areas proposed for the exclusion zones represent 12% of the U.S. population, but 17% of the value weighted population.[41] See Table 1.

Table 1
Penalty on Spectrum Value Based on Exclusion Zones

		Population		
		Excluded Zones [1]	Total US [2]	Percent of Total [3]
Population	[A]	34,551,579	285,620,445	12%
Value Weighted Population	[B]	48,404,502	285,615,408	17%

Source and Notes:
[A] [1]: Population for excluded zones calculated by The Brattle Group through GIS. Excluded zones based on: U.S. Department of Commerice. "An Assessment of the Near-Term Viability of Accomodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 43980-4400 MHz Bands." October 2010, p.5-2.
[A] [2] : www.fcc.gov, Auction 66 results.
[B] [1] : Excluded population weighted by the relative value of CMA markets from Auction 66.
[B] [2] : Total population weighted by the relative value of CMA markets from Auction 66.
[3] : [1] / [2].

ILLUSTRATIVE IMPACTS

AWS-3: 1755 MHz Valuation

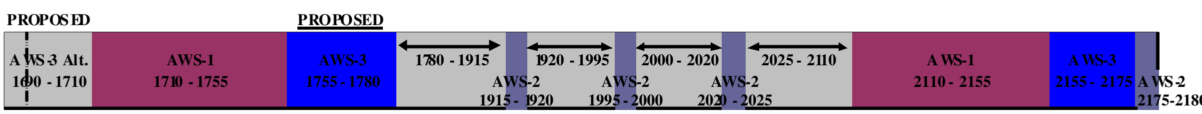
In a well-functioning market, buyers have the incentive to accurately reveal and pay up to their true value for an asset. Under these circumstances, the value of a capital asset is best reflected by the price users are willing to pay for it. For spectrum licenses, this market value is captured either by the sale price in a well-structured auction or the contracted price in a private license transfer, provided a liquid market exists. Since the FCC has not yet issued licenses for the AWS-3 band, historical pricing information is not available. In the absence of direct AWS-3 pricing, the best alternative is to compare its value to that of other existing spectrum licenses

[40] See *NTIA Report*.
[41] This report does not analyze any potential exclusion zones for the 1755 MHz band.

with known value, and adjust for factors that are likely to impact the relative value between the two bands.

Based on its quality and characteristics, the AWS-1 band is the most comparable band to the AWS-3 band. Assuming AWS-3 is paired with 20 MHz of spectrum in the 1755 MHz – 1780 MHz band, the two share a number of qualities that typically impact spectrum value. First, both the uplink and downlink bands of AWS-1 and AWS-3 would be adjacent (see Figure 1). As a result, their spectrum wavelengths have similar signal characteristics and equal duplex spacing between pairs. In fact, if AWS-3 was paired with 1755 MHz – 1780 MHz, then AWS-1 and AWS-3 would be similarly harmonized. Devices designed for the AWS-1 band then could be easily modified for the paired AWS-3 spectrum.[42] These bands also share many of the same fixed microwave federal incumbents.[43] Relocation challenges for the two bands are so similar that the FCC requires that both AWS-1 and future AWS-3 license holders share the cost of clearing encumbrances.[44] From the bidder’s perspective the 1755 MHz clearing costs are similar to AWS-1 clearing costs because the direct costs are covered by the federal government, possibly out of auction revenues.[45] Since the AWS-1 auction in September 2006 was competitive, its results are likely to reflect AWS spectrum value.[46]

Figure 1. AWS Bands



Assuming the 20 MHz of spectrum in the 1755 MHz – 1780 MHz band is paired with the AWS-3 band, the combined 40 MHz of spectrum would be worth nearly $12 billion. Table 2 outlines this calculation. The average auction price of the AWS-1 spectrum in 2006 was $0.54/MHz-Pop. This price needs to be adjusted to account for the change in spectrum value over time. According to the SpecEx Spectrum Index, the value of spectrum increased 94% between September 18, 2006 and April 7, 2011.[47] Updating the average price of AWS-1 spectrum by this percentage provides a current price of $1.05/MHz-pop.[48] This price implies

42 “In the Matter of Office of Engineering and Technology Requests Information on Use of 1675 – 1710 MHz Band.” *Comments of CTIA – The Wireless Association* before the FCC, ET Docket No. 10-123, June 28, 2010.

43 *Ibid.*, p.6.

44 “Ninth Report and Order.” FCC 06-45. Some of the incumbents to the AWS-1 spectrum also use some AWS-3 spectrum. Under the rules set out in the Ninth Report and Order, once AWS-3 licenses are assigned, the AWS-3 license holders will have to compensate AWS-1 license holders who have already cleared incumbents from the AWS-3 in their effort to clear incumbents from the AWS-1 spectrum.

45 Should the value of the spectrum at auction not be sufficient to cover the clearing costs, then the reallocation should not take place.

46 Bulow, Jeremy, Jonathan Levine and Paul Milgram. “Winning Play in Spectrum Auctions.” *NBER* Working Paper No. 14765, March 2009.

47 SpecEx Spectrum Index from Spectrum Bridge® values of 156 on September 18, 2006 and 303 on April 7, 2011 retrieved April 2011 from <http://spectrumbridge.com/products-services/specex/index.aspx>.

48 In this analysis I do not take account of the impact of the increased amount of spectrum available for mobile broadband services on the price of spectrum. The current proposal only increases total licensed spectrum

that the total value for the 40 MHz of spectrum is nearly $12 billion assuming a U.S. population of 286 million.[49]

Table 2
Implied AWS-3 Spectrum Value from AWS-1 Auction Results

			AWS-1 Auction Value 9/18/2006 *[1]*	Current Value 4/7/2011 *[2]*
Spectrum Index Value				
SpecEx	[A]		156	303
SpecEx Percentage Change	[B]	%		94%
Base Population	[C]		285,620,445	285,620,445
Spectrum Band Size	[D]	MHz	90	40
AWS Value				
AWS-1 Total Value	[E]	$	$13,879,110,200	
AWS Average Price	[F]	$/MHz-Pop	$0.54	$1.05
Projected AWS-3 Paired with 1755 MHz Value	[G]	$		**$11,981,112,224**
Unpaired Spectrum Value as a Percent of Paired Spectrum	[H]	%		60%
Updated AWS Average Price for Unpaired Spectrum	[I]	$/MHz-Pop		$0.63
Unpaired Spectrum Band Size	[J]	MHz		20
Projected AWS-3 Unpaired Value	[K]	$		**$3,619,835,261**

Source and Notes:
[A]: SpecEx Spectrum Index values downloaded from http://spectrumbridge.com/products-services/specex/index.aspx (accessed 4/7/2011).
[B]: ([A][2]-[A][1])/[A][1].
[C]: FCC population estimates based on Census 2000 data aggregated by basic trading area (BTA).
[D][1], [E]: Auction 66 results downloaded from FCC Auctions at http://wireless.fcc.gov/auctions.
[D][2]: Based on FCC proposal to pair the AWS-3 2155 MHz - 2175 MHz band with 20 MHz of spectrum between 1755 MHz - 1780 MHz.
[F][1]: [E][1]/([C][1]*[D][1]). [F][[2]: [F][1]*(1+[B][2])
[G]: [F][2]*[D][2]*[C][2].
[H]: The average price from the A, B and C block of the 700 MHz auction was $1.36/MHz-pop. The average price for the E block was $0.74 MHz-pop, 54% of the average price for the three paired licenses. A recent AT&T Qualcomm sales of the E-block spectrum suggests that the value of unpaired spectrum has increased to $0.63 MHz-pop.
[I]: [F][2]*[H][2].
[J]: Based on scenario in which the AWS-3 2155 MHz - 2175 MHz remains unpaired.
[K]: [C][2]*[I][2]*[J][2].

by a few percentage points, making its impact on the spectrum price level minimal. For a fuller explanation of how to take account of this effect, see, Coleman Bazelon "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations." Sponsored by *Consumer Electronics Association*, 2009.

[49] For consistency of estimates and calculations, I use the Census 2000 population values used by the FCC.

AWS-3 Unpaired Valuation

By contrast, assuming that the AWS-3 band remains unpaired, the expected value for the 20 MHz of spectrum in the 2155 – 2175 MHz band is about $3.6 billion. To find a discount for unpaired spectrum, I use the observed discount from the 700 MHz auction. As noted above, in the FCC's auction of 700 MHz spectrum in 2008, the average price for unpaired spectrum was 54% of the price for paired spectrum, which translates to a 46% discount.[50] The recent AT&T acquisition of unpaired 700 MHz licenses from Qualcomm updates this relation of unpaired to paired spectrum value to 60%.[51] If the updated average price for paired spectrum is $1.05/MHz-pop, this implies that the average price for unpaired spectrum is $0.63/MHz-pop. The expected value for all 20 MHz of AWS-3 spectrum nationwide would be just over $3.6 billion.

Estimated Difference for Pairing with 1690 MHz vs 1755 MHz Spectrum

Pairing the AWS-3 with the 1690 MHz – 1710 MHz spectrum band will incrementally decrease its value through increased costs and uncertainty regarding equipment, thereby diminishing cash flow, future profits, and present value. The three cost shifts examined here are the expected increase in costs of devices and network equipment, as well as the added risks to expected future cash flows from developing the band. There may be additional costs to pairing AWS-3 with the 1690 MHz band not addressed here; to the extent additional costs are identified, they would flow through to reduce profits and lower net present value in ways similar to those described here.

The effects of increased costs and uncertainty are estimated through a generalized cash flow model. The essential feature of the model is an initial period of negative cash flows, followed by growing profits. To simplify the calculations, I assume that once the cumulative net present value of cash flows is zero, the model is in equilibrium. This is equivalent to a number of years of zero profits (the period over which the cumulative net present value of cash flows is zero) followed by a steadily growing stream of profits. This assumption allows me to model various expenses, such as amortized capital expenses and consumer equipment subsidies, as a fixed share of revenues, thus significantly simplifying the calculations.

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[50] Based on the price difference between the E Block and the A, B and C blocks. See <www.fcc.gov/auctions> for details.

[51] This value may only represent an upper bound of the unpaired-to-paired ratio because this sale from Qualcomm to AT&T coincided with a commitment by Qualcomm to build chipsets to use the band. See, "Qualcomm Announces Agreement for Sale of 700 MHz Spectrum Licenses." December 20, 2010 available at <http://www.qualcomm.com/news/releases/2010/12/20/qualcomm-announces-agreement-sale-700-mhz-spectrum-licenses> for Qualcomm's integration of carrier aggregation technology into its chipset roadmap for use in unpaired spectrum bands. AT&T plans to use this technology once compatible equipment is developed, see, "AT&T Agrees to Acquire Wireless Spectrum from Qualcomm." December 20, 2010 available at <http://www.qualcomm.com/news/releases/2010/ 12/20/att-agrees-acquire-wireless-spectrum-qualcomm>. Furthermore, because of its existing 700 MHz license holdings, AT&T was uniquely positioned to most efficiently use Qualcomm's spectrum.

As discussed above, one concern with the 1690 MHz – 1710 MHz band is the requirement for non-standard customer devices, such as handsets and computer dongles. Higher research and development costs, and lower demand for a non-standard device implies increased cost per device. For service providers, higher device costs are reflected on their balance sheet as increased cost of equipment, including additional device subsidies, rebates and customer concessions. The expected increase in device costs associated with a pairing with the 1690 MHz band are conservatively estimated to be about $5 per device.[52] This added cost can be modeled as an increase in equipment subsidies. A $5 increase in equipment subsidies represents about a 3% increase in such subsidies. As Table 3 illustrates, assuming equipment costs are 18 percent of revenue for the 1755 MHz band, a 3% increase in device costs implies that equipment costs would be 18.5% of revenue for the 1690 MHz band. Such increased cost further results in a 2.2% discount to the present value of cash flow. Based on the device penalty alone, the present value of cash flow for the 1690 MHz band is 2.2% lower than the present value of cash flow for the 1755 MHz pairing. If the value of the 1755 MHz pairing is almost $12 billion, this translates to a decrease of $264 million.

A second concern with the 1690 MHz band pairing is the increased network equipment costs. Pairing with the 1690 MHz band will require additional or modified infrastructure. For instance, existing radios will have to be upgraded to extend beyond the existing wavelengths or new radios will have to be developed. An increased capital cost of 10%[53] increases the amortized capital costs from 12% of revenues to 13.2% of revenues. Increased capital costs also increases operating costs, or cost of service. The cost of service increases 1.5 percentage points, from 15% to 16.5%. Combined, these costs result in a 10.8% decrease in the present value of cash flows. Based on the expected increase in network equipment costs alone, the present value of cash flow for the 1690 MHz band is 10.8% lower than the present value of cash flow for the 1755 MHz pairing or about $1.296 billion.

The cumulative effect of both the expected higher customer device and network equipment costs is a reduction in cash flows of about 13%. Such a reduction in profits would be expected to reduce the value of the band by about $1.56 billion.

[52] Based on conversations with industry engineers.

[53] Discussions with industry engineers indicated these additional costs could be in the range of $1 billion. 10% increase in capital costs as a percentage of revenue is a rough approximation of the impact of $1 billion in added costs to a 40 MHz mobile broadband network.

Table 3
AWS-3 Band Value
Cash Flow for 1690 MHz Pairing as Percent of 1755 MHz Pairing

Basic Cash Flow Assumptions (For 1755 MHz)		**Factor**
Cost, amortized capital (% of revenue)	[A]	12.0%
Cost, service (% of revenue)	[B]	15.0%
Cost, equipment (% of revenue)	[C]	18.0%
Cost, SGA (% of revenue)	[D]	30.0%
Cash Flow (% of revenue)	[E]	25.0%
Penalties		
Capital Cost Increase	[F]	10.0%
Device Penalty	[G]	3.0%
Updated Costs for 1690 MHz - 1710 MHz Band		
Cost, amortized capital (% of revenue)	[H]	13.2%
Cost, service (% of revenue)	[I]	16.5%
Cost, equipment (% of revenue)	[J]	18.5%
Cost, SGA (% of revenue)	[K]	30.0%
Implied Cash Flow for 1690 MHz - 1710 MHz Band		
Cash Flow Including Device Penalty (% of revenue)	[L]	24.5%
Cash Flow Including Device Penalty (% of 1755 MHz Cash Flow)	[M]	97.8%
Discount for Device Penalty (% of 1755 MHz Cash Flow)	[N]	2.2%
Cash Flow Including Network Infrastructure Penalty (% of revenue)	[O]	22.3%
Cash Flow Including Network Infrastructure Penalty (% of 1755 MHz Cash Flow)	[P]	89.2%
Discount for Network Infrastructure Penalty (% of 1755 MHz Cash Flow)	[Q]	10.8%
Cash Flow Including Device & Network Infrastructure Penalty (% of revenue)	[R]	21.8%
Cash Flow Including Device & Network Infrastructure Penalty (% of 1755 MHz Cash Flow)	[S]	87.0%
Discount for Device & Network Infrastructure Penalty (% of 1755 MHz Cash Flow)	[T]	13.0%

[A]-[D]: Cash flow assumptions based on observations from public income statements of three wireless carriers' (i.e., Verizon Cellco, Sprint Wireless, U.S. Cellular) for 2007 through 2009, and fall within the range of minimum and maximum percentages for each line item.

[E]: 1-[A]-[B]-[C]-[D].
[F]: Brattle assumptions based on conversations with industry engineers and officials.
[G]: Brattle assumptions based on conversations with industry engineers and officials.
[H]: [A] x (1+[F]).
[I]: [B] x (1+[F]).
[J]: [C] x (1+[G]).
[K]: [D].
[L]: 1-[A]-[B]-[D]-[J].
[M]: [L]/[E].
[N]: 1-[M].
[O]: 1-[C]-[D]-[H]-[I].
[P]: [O]/[E].
[Q]: 1-[P].
[R]: 1-[H]-[I]-[J]-[K].
[S]: [R]/[E].
[T]: 1-[S].

In addition to the change in the expected costs of equipment, the un-harmonized 1690 MHz – 1710 MHz band implies additional risks that do not exist for the 1755 MHz – 1780 MHz band. Certainly, every enterprise incurs some risk of doing business. Some portion of this risk is inherent to the entire economy, while the rest is unique to the industry. Industry specific risks often include general economic risk and market failures, technological uncertainties related to research and development, and the possibility of accidents. These general market and industry specific risks and uncertainties are reflected in the industry cost of capital, defined as the weighted average return from debt and equity by firms in the industry. The cost of capital, therefore, reflects the industry specific business cycles. For telecom services, this cost of capital is estimated to be 7.4%.[54]

In addition to telecom service risks, the 1690 MHz – 1710 MHz band bears risks associated with equipment, particularly non-standard devices. For instance, it is not clear how long technological development will take, or whether the devices will have features comparable to standard counterparts. It may be that only higher end devices are developed initially. Whether equipment manufacturers find the required R&D worth undertaking, and on what time table, is susceptible to industry risk. Given the limited demand for non-standard devices, the extent to which manufacturers devote resources to their development and production is dependent on other market factors, including excess engineering capacity and demand for other goods.

One very important point about this increased risk and uncertainty about additional costs is that higher than expected costs or longer than expected delays are more likely in times of high demand for mobile services. That is, in boom times resources are less likely to be devoted to the development of devices for non-standard bands. This is more costly because the losses (when times are good) are likely to be larger than the gains (in bad times when costs are not higher or delays are shorter.)

To control for these additional uncertainties related to the telecom equipment, I apply the cost of capital for the telecom equipment industry to the valuation of the 1690 MHz pairing.[55] The cost of capital for telecom equipment is 8.2%[56], a little more than three quarters of a percentage point higher than for telecom services. This difference is suggestive of the additional risk from increased equipment uncertainty. If the increased risk was higher or lower than this amount, the impact on spectrum value would similarly be higher or lower.

To estimate the impact of a higher cost of capital on the net present value of profits, I model more specific cash flows. In order to calculate relative NPV for the 1755 MHz pairing, we assume that revenue ramps up over five years such that cash flow is positive in year five. Based on a constant five percent revenue growth from the fifth year on, the cumulative NPV is

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[54] Downloaded on April 7, 2011 from <http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/wacc.htm>.

[55] For additional resources on the added cost of non-standard devices for the 1690 MHz band, see, Varrall, Geoff. "RF Cost Economics for Handsets." *RTT* white paper, May 2007 <www.rttonline.com/research/RFCostEconomicsForHandsets-study.pdf>; "In the Matter of Office of Engineering and Technology Requests Information on Use of 1675 – 1710 MHz Band." *Comments of CTIA – The Wireless Association* before the FCC, ET Docket No. 10-123, June 28, 2010; "In the Matter of Relocation of Federal Systems." *Comments of 3G Americas* before the NTIA, Docket No 0906231085-91085-01.

[56] Downloaded on April 7, 2011 from <http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/wacc.htm>.

positive beginning seven years after the initial investment.[57] Assuming that the 1690 MHz band had the same general cost structure as the 1755 MHz band, the effect on the net present value from the higher discount rate on the AWS-3 pairing with the 1690 MHz – 1710 MHz band is 72% of the NPV from pairing with the 1755 MHz – 1780 MHz band. See Table 4. Assuming the value of the 1755 MHz band is almost $12 billion, this translates into a reduction in value of $3 billion.

The decreased value from the higher expected equipment cost is done in two steps. First, the higher equipment costs associated with the 1690 MHz pair delays the cumulative NPV break-even point by one year. In the context of higher costs and risk, cash flow is still positive in year five but the cumulative NPV does not turn positive until year eight.[58] This one year penalty decreases the NPV of the 1960 MHz pairing to 70% of the 1755 MHz band pairing. Finally, adding the higher expected equipment costs to the network infrastructure costs, the NPV of the 1690 MHz band pairing is 61% of the NPV of the 1755 MHz pairing or a reduction of $4.7 billion.

[57] Specifically, we assume that depreciation begins in year 1 at 12% of anticipated revenue at maturity. Actual revenue begins to ramp up in year 2, beginning with 12.5% of cash flow at maturity and doubling annually until it reaches maturity in year 5. Once revenue has reached maturity in year 5 it increases at 5% per year in perpetuity. Cost of service is 15% of revenue at maturity beginning in year 2. Equipment costs and SGA costs both ramp up with revenues, to 18% and 30% of revenues respectively in year 5.

[58] Assuming depreciation begins in year 1 at 12% of steady state revenue, cost of service begins in year 2 at 15% of steady state revenue, and other operating costs ramp up with actual revenues similar to the 1755 MHz band (see Table 3). Consistent with our earlier assumptions, by year 5, cost of equipment is 15% of revenues and SGA costs are 30% of revenues.

Table 4
AWS-3 Band Value
NPV for 1690 MHz Pairing Versus 1755 MHz Pairing

		Factor
Annual Growth in Cash Flow	[A]	5.0%
Cost of Capital, Telecom Services	[B]	7.4%
Cost of Capital, Telecom Equipment	[C]	8.2%
1755 - 1780 MHz NPV (as a Multiple of Annual Cash Flow)	[D]	38.4
1690 - 1710 MHz NPV (as a Multiple of Annual Cash Flow)		
Assuming Higher Equipment Cost of Capital, breaking-even in year 7	[E]	27.6
Assuming Higher Equipment Cost of Capital, breaking-even in year 8	[F]	26.8
Including Device & Network InfrastructureCost Discounts, assuming Equip. Cost of Cap, breaking even in year 8	[G]	23.3
NPV for 1690 - 1710 MHz Band as Percent of 1755 - 1780 MHz Band		
Assuming Higher Equipment Cost of Capital, breaking-even in year 7	[H]	72%
Assuming Higher Equipment Cost of Capital, breaking-even in year 8	[I]	70%
Including Device & Network Infrastructure Cost Discounts, assuming Equip. Cost of Cap, breaking even in year 8	[J]	61%

Source and Notes:
[A]: Brattle assumption.
[B], [C]: Downloaded from http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/wacc.htm on 4/7/2010.
[D]-[G]: Brattle calculations.
[H]: [E]/[D].
[I]: [F]/[D].
[J]: [G]/[D].

ASYMMETRIC PAIRING

The NTIA has proposed freeing 15 MHz from government use in the 1695 MHz to 1710 MHz band. This 15 MHz could be paired with the 20 MHz of the AWS-3 band. If this asymmetric pairing occurs, it would be the first time such an allocation was created in a significant band intended for mobile broadband. Clearly, other things equal, the value of pairing the AWS-3 band with 15 MHz of spectrum is less than pairing it with 20 MHz of spectrum. Because we have no direct experience with such an allocation, we cannot predict with precision what an appropriate discount would be. Nevertheless, a close approximation of the value can be found by looking at a pair of transactions that replicate the asymmetric pairing proposed: the value of 15 MHz of paired spectrum, plus the value of 5 MHz of unpaired spectrum.

The recent AT&T acquisition of unpaired 700 MHz licenses from Qualcomm is one likely comparison for adding asymmetric capacity. The analysis calculated above estimated that the $/MHz-pop value of unpaired spectrum was 60% of the value of paired spectrum. The proposed asymmetric pair would limit the spectrum to 35 MHz and reduce the MHz-pops of the allocation by 12.5%.[59] The unpaired 5 MHz of spectrum in the allocation represents another 12.5% of the MHz-pops that are valued at 60% of the optimally paired allocation. This implies that the value of the asymmetric pairing including the band penalties and additional uncertainty is 53% of the symmetric pairing with the 1755 MHz – 1775 MHz band.[60] Consequently, the additional cost of the asymmetric 1690 MHz band pairing is just less than 8%, or $1.0 billion.

CONCLUSION

As demand for mobile broadband services increases, efficient allocation of spectrum for wireless uses is essential. Ensuring that the AWS-3 band is paired to create the most capacity and highest spectrum value possible is central to this goal. To this end, this paper compares the value of pairing the AWS-3 with the 1755 MHz band to the value of pairing it with the 1690 MHz band, pairing it with the 15 MHz of the 1695 MHz band, or leaving the AWS-3 band unpaired. See Table 5. Drawing on the results of the value of the FCC AWS-1 auction, this paper estimates that the value of the AWS-3 band symmetrically paired with the 1755 MHz band is approximately $12 billion, assuming a well designed auction. Based on the additional costs of deploying the 1690 MHz band, including higher device costs, additional capital expenditures, and increased uncertainty are likely to decrease the spectrum value for the paired 40 MHz by 39% to $7.3 billion. An asymmetric pairing, combined with the equipment and infrastructure penalties and uncertainty, will result in a total of 35 MHz reducing the spectrum value by 47% to $6.4 billion. Proposed exclusion zones associated with the 1695 MHz band would reduce the value by another $1.1 billion to $5.3 billion or just 44% of the value of the 1755 MHz pairing. This amounts to a total loss of $6.7 billion from the optimally paired spectrum. While the added costs of the 1690 MHz band pairing leads to substantial loss in value, either pairing is preferred to leaving the AWS-3 unpaired. An unpaired AWS-3 is likely to receive $3.6 billion in auction receipts.

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[59] (40 MHz – 35 MHz)/40 MHz.

[60] This cumulative discount represents the weighted average discount of: (1) 30 MHz (75% of MHz-pops) of paired 1695 MHz – 1710 MHz spectrum at a 39% discount; (2) 5 MHz (12.5% of MHz-pops) of unpaired spectrum at a 40% discount; and (3) 5 MHz (12.5% of MHz-pops) of lost spectrum. Mathematically, the expression is (30 MHz * 61% + 5 MHz * 60% + 5 MHz * 0%)/40 MHz.

Table 5
AWS-3 Band Value
Estimated Value of the 1755 MHz Pair, 1690 MHz Pair and Unpaired

		Cumulative Discount *[1]*	Estimated Value *[2]*
1755 MHz Paired (40 MHz) Value	[A]		$11,981,112,224
Unpaired (20 MHz) Value	[B]		$3,619,835,261
Discounted 1690 MHz Paired (40 MHz) Value			
Including Device and Network Infrastructure Penalties	[C]	13%	$10,428,360,080
Including Device and Network Infrastructure Penalties and Added Equipment Uncertainty	[D]	39%	$7,279,982,126
Asymmetrically Paired and Discounted 1690 MHz (35 MHz) Value			
Asymmetric Spectrum (5 MHz)	[E]		$904,958,815
Including Device and Network Infrastructure Penalties (30 MHz)	[F]		$7,821,270,060
Total (35 MHz) Value With Penalties	[G]	27%	$8,726,228,875
Including Device and Network Infrastructure Penalties and Added Equipment Uncertainty (30MHz)	[H]		$5,459,986,594
Total (35 MHz) Value With Penalties and Uncertainty	[I]	47%	$6,364,945,410
Penalty Based on Excluded Population	[J]		17%
Total (35 MHz) Value With Penalties, Uncertainty, and Excluded Population Penalty	[K]	56%	$5,286,250,066

Source and Notes:
[A], [B], [C][1], [D][1]: Brattle analysis above in Tables 2 - 4.
[C][2]: [A][2]*(1-[C][1]).
[D][2]: [A][2]*(1-[D][1]).
[E][2]: [A][2]*(1-0.4)*(5/40).
[F][2]: [C][2]*(30/40).
[G][1]: (1-[G][2]/[A][2]).
[G][2]: [E][2]+[F][2].
[H][2]: [D][2]*(30/40).
[I][1]: (1-[I][2]/[A][2]).
[I][2]: [E][2]+[H][2].
[J]: Table 1.
[K]: (1-[J])*[I].