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Increasing the Efficiency of Spectrum Allocation

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Abstract Over the past 80 years, the Federal Communications Commission has been responsible for the allocation of non-governmental use of the radio frequency spectrum. Over that time, here have been significant changes in spectrum use that have been driven by changes in demand and technology. The technical, regulatory, and business obstacles in past reallocations shed light on some of the FCC's implementation decisions for its upcoming two-sided auction.

1 Forces That Have Led to Changes in Spectrum Use Over Time

Spectrum is used for a wide variety of wireless services: broadcast radio, television, point-to-point microwave, satellite, radar, and many others. Allocating spectrum among competing non-Federal uses is one of the fundamental duties that the 1934 Communications Act assigned to the Federal Communications Commission (FCC or Commission).[1] The FCC historically has determined what services and technologies can make use of specific frequencies of the electromagnetic spectrum through

[1] Section 303 of the Communications Act of 1934, as Amended: http://www.house.gov/legcoun/Comps/FCC_CMD.PDF:page152.

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an administrative rulemaking process.[2] Typically, the FCC puts different services in different parts of the spectrum (bands), although there are many exceptions where two or more uses share bands. This entire planning process, from the earliest stage through rulemaking and licensing, can take many years.

Despite whatever success the Commission had at determining an optimal combination of service and technology at any point in time, continuing changes in consumer preferences and technology eventually cause that combination to become suboptimal. As the divergence between the value in the current service and in potential new uses increases, so do the gains from reallocation. In other words, the overall allocation process should strive to be both statically and dynamically efficient.

Technology has changed the nature and economics of both wireless and wireline communication services, and these technological advances have interacted with communications policy and have led to a much greater variety of services available to consumers (Rosston 2014). Wireless technology has advanced, most importantly with the advent of cellular architecture, digital technology, satellite systems, and Wi-Fi. At the same time, the introduction of cable television systems, fiber optic backhaul, and the Internet have changed the nature of substitutes and complements for spectrum-based services.

As new mobile wireless devices have become available, consumer demand for mobile wireless services has increased dramatically. In just the past 10 years, more than one-third of households have given up wired home phone service entirely, and apparently are relying instead on phone service from their wireless provider.[3] Consumers are also increasingly accessing the Internet over mobile devices for a variety of applications, including streaming video.

Starting with Coase (1959), economists have argued for market allocation of spectrum.[4] Subsequently, there have been a large number of authors who have advocated that spectrum allocations should permit greater flexibility of use.[5] With the introduction of cellular service, which was first commercially licensed in 1984, the FCC not only repurposed a large amount of spectrum (115 MHz) but provided greater flexibility with the introduction of more flexible licenses that covered large spectrum blocks and geographic areas within which cellular licensees could deploy mul-

[2] Allocations are usually followed by one or more additional rulemaking proceedings to determine the detailed technical and licensing rules for each use (service). For services that require a license, a period is then set for filing applications. If more applications are filed than can be granted, a procedure is followed for deciding which ones will be granted and which ones denied. Licenses for most commercial services (certain satellite services being an exception) are now awarded through competitive bidding (auction), but historically were awarded based on comparative hearings and later for a short period of time by lottery. Applications for non-commercial uses (amateur, public safety, etc.) are typically not mutually exclusive and can thus be granted as received as long as eligibility and other rules are met. Certain low-power transmitters—such as Part 15 devices (e.g., Bluetooth, cordless phones, garage door openers, etc.), Wi-Fi, and wireless microphones—do not require a license at all.

[3] Blumberg and Luke (2013). But at the same time, about 90 million homes (above 2/3 of U.S. homes) have a wired broadband service that could provide telephone service at low incremental cost, Federal Communications Commission (2013).

[4] Coase attributes the idea of auctioning spectrum licenses to Herzel (1951).

[5] See for example, DeVany and Eckert (1969), Webbink (1980), Rosston and Steinberg (1997), Hazlett (2001), and White (2001).

tiple, low-power base stations and reuse assigned frequencies as needed to meet demand.

Prior to this increased flexibility, the FCC licensed each base station to operate on a particular frequency at a specific location to cover an area with a single high-power transmitter. In its initial cellular decisions the FCC continued its practice of requiring licensees to use a specific technical standard and to provide a specific service: mobile voice. In contrast, the 1994 Personal Communication Service ("PCS") allocation (which also repurposed spectrum) had very few restrictions on either service or technology beyond those that were meant to control interference.

The combination of technological advances and changes in demand and supply provided motivation for the movement of spectrum from initial allocations to more valuable uses over time. The FCC's increasing reliance on market-based spectrum policies has facilitated the movement. Of course, reallocations would not have occurred without pressure from interest groups: service providers, consumers, and politicians who were interested in potential auction revenue. At the same time, some constituencies have opposed these moves: e.g., institutional advocates of services that stand to lose spectrum, incumbents who face potential interference or relocations, and companies that were concerned about potential competition from those that were granted greater flexibility.

This paper examines several important examples of changes in spectrum use and highlights some of the complex issues that have been encountered as well as the roles of the FCC and private market actors in facilitating those transitions. There have been three main regimes for the transition of spectrum from one use to another: mandates by the FCC; initiatives by incumbent licensees to acquire additional rights with the approval and facilitation of the FCC; and most recently, the introduction of a two-sided auction to reallocate spectrum from broadcast to mobile broadband use voluntarily while simultaneously repacking incumbents in a reduced amount of spectrum and re-structuring cleared spectrum to maximize its value for mobile wireless.

The case studies in Sects. 3 and 4 illustrate technical, regulatory, and business obstacles that have hampered the move toward more efficient spectrum use. The lessons from these case studies shed light on some of the decisions the FCC has made and will have to make in implementing its upcoming two-sided auction.

2 Alternative Mechanisms to Transition Spectrum to New Uses

Typically, the initiative for reallocation comes from those hoping to benefit from the introduction of a new service. As mentioned above, there are three basic approaches for bringing about such reallocations: In the first, the FCC proposes a change in allocation through an administrative (rule making) process, often in response to a petition from a proponent of a new use or technology. In the second, companies initiate a reallocation by purchasing licenses (in private transactions) that have been used for one purpose and then asking the FCC for approval of the new use of that spectrum, often with accompanying rule changes.

The third mechanism, authorized by Congress in 2012 and currently under development by the FCC, is a two-sided "incentive" auction to determine spectrum supply as well as demand. In the first such auction—the Broadcast Television Incentive Auction, which is scheduled for 2015—the FCC will (1) pay TV licensees who bid to relinquish UHF spectrum; (2) repack the remaining TV licensees onto a smaller number of channels at the lower end of the current TV band; (3) consolidate the cleared spectrum at the upper end of the band into new flexible use licenses (frequency blocks and geographic areas) that are appropriate for mobile broadband; and (4) auction the newly created wireless licenses.[6]

When it uses the first mechanism the government acts in a traditional central planning role in promoting a new use for spectrum using the administrative process.[7] With the second mechanism the government facilitates and ratifies private market transactions aimed at changing spectrum use. Under of the third approach the government designs and implements a mechanism that combines features of markets and government spectrum planning as a more efficient way to repurpose spectrum from lower- to higher-valued use.[8]

3 Government-Mandated Reallocations

Historically, the FCC has mandated reallocations from one use to another through a public rulemaking proceeding that it initiates when it, or more typically an outside party, proposes a new use and a band reallocation to accommodate that use. When spectrum was lightly used, accommodating new uses was often possible with little or no impact on existing uses as the rapid advance of radio technology opened vast expanses of unoccupied spectrum at higher frequencies. Eventually, however, even these higher frequencies became fully allocated, requiring that currently allocated, and even occupied, spectrum be repurposed.

Repurposing spectrum not only requires that the definition of permissible use of the band be changed, but that service rules appropriate for the new use be adopted. Service rules typically include technical limits to prevent interference (maximum power, etc.), in some cases a mandatory technology standard, and licensing rules to determine who is eligible for the new licenses and how mutually exclusive applications are resolved. The repurposing of heavily encumbered bands may also require rules that specify how incumbents are to be protected from interference (or cleared) and who is responsible for the costs that are incurred. The FCC may also provide an alternative band to which incumbents can be moved.

[6] See Kwerel and Williams (2002) for the first explanation of how a centralized auction could increase the efficiency of moving spectrum to more highly valued uses.

[7] The term "new use" refers to a *change in use* of spectrum through repurposing, which can be to accommodate an entirely new use or expansion of an existing use.

[8] Although not discussed in this paper, a possible fourth method based on dynamic sharing technology is getting current attention and may become important in the future as a means of repurposing unused spectrum in Government and possibly other bands without the need to relocate incumbents. See President's Council of Advisors on Science and Technology (2012).

3.1 The First Repurposing of Television Spectrum and the Emergence of Cellular Technology

3.1.1 Higher Valued Use: New Cellular Technology

AT&T developed the concept of cellular radio systems in the 1940s. In 1968, the FCC initiated a proceeding to repurpose 115 MHz of spectrum in the 800 and 900 MHz bands from UHF TV broadcasting (channels 70–83), the Federal Government, microwave ovens, and other uses to the land mobile service. Seventy-five (75) MHz were targeted for a new high capacity common carrier mobile telephone service based on a cellular architecture that allowed for extensive geographic re-use of spectrum. The remaining 40 MHz were proposed for private land mobile use specifically targeted for more efficient multi-channel trunked technology. The FCC adopted the proposed reallocation two years later.

The reallocation proposed in 1968 was the result of over a decade of study and debate about the need for more spectrum for land mobile services in general, and in particular to expand the offerings of the early common carrier mobile telephone systems that were grossly inadequate for the demand. The growth of UHF TV service had been slower than expected and serious congestion was occurring in the existing private and common carrier land mobile bands.

However, the ultimate demand for expanded common carrier land mobile service was uncertain and technology feasibility and costs for high capacity cellular-type systems were largely unknown. The FCC did not know the minimum efficient scale for a cellular system, either in geography or the amount of spectrum needed. In its Second Report and Order, the FCC noted that submissions proposed spectrum block sizes that ranged from 5 to 64 MHz. The FCC decided that it would allocate 40 MHz to a single cellular system operator and hold additional spectrum adjacent to that block in reserve.

3.1.2 Clearing Incumbents: No Compensation But Lengthy Amortization Period

To make the 800 MHz spectrum available for land mobile radio use the FCC ceased assigning new broadcasters to channels 70–83 and relocated incumbents to lower channels. There were two regular TV stations and 600 "translators" that operated in channels 70–83.[9] Initially the translators were proposed to stay on a co-equal basis with the new land mobile systems. Later, the translators were also relocated to lower channels. Given that the FCC provided replacement channels and allowed stations to stay until their channels were actually needed for cellular use (early 1980s) there was little practical loss to the incumbents.

9 FCC (1968) at par. 11. A "translator" extends the range of a broadcast signal by receiving the signal from the primary broadcast antenna and rebroadcasting the signal on a different channel.

3.1.3 Flexibility: Large Blocks and Areas; Mandatory Technology and Service Requirements

The FCC mandated that cellular licensees use the Analog Mobile Phone Standard (AMPS) when they began operation.[10] The FCC wanted to ensure that there would be nationwide compatibility so that users could "roam" (or more accurately at that point in time, drive) to different areas and still be able to obtain service. In addition, consumers could switch providers since at that time handsets spanned the entire cellular spectrum allocation and were not tied to one specific provider.

The FCC also mandated that initial cellular licenses provide a specific service: interconnected voice services. In fact, the FCC prohibited traditional wireless "dispatch" service on cellular systems because it thought that such service was a technically inefficient use of the cellular technology and was better suited to traditional high-power, wide-area wireless systems, for which the Commission had made a separate allocation.[11] The FCC adopted mandatory build out rules to ensure that the intended service would be provided over the licensed area.

Despite these mandates, cellular licenses that covered a large spectrum block and geographic area were inherently more flexible than were licenses for prior systems. Many of the details of system design were left to licensees, who had flexibility in determining the number and location of the cell towers necessary to provide geographic coverage and adequate capacity to meet growing demand.[12]

With the introduction of digital technology in the 1990s, the FCC took a less prescriptive approach to cellular standards. It did not mandate any specific digital standard for cellular systems, but did mandate that they continue to offer AMPS service until 2008.[13] In addition, the FCC relaxed its prohibition on the offering of dispatch services and allowed for data services on cellular and all commercial mobile radio services (CMRS) spectrum.

3.1.4 Competition Policy: Two Competitors Per Market

Initially, the FCC proposed to license a single cellular system in each area to the incumbent wireline telephone company. However, in the late 1970s, the government was moving to deregulation and competition in areas such as trucking and airlines. In telecommunications, the Department of Justice was pursuing its antitrust suit against AT&T, and MCI was a fledgling entrant into long distance service.

[10] The FCC adopted the AMPS standard in the early 1980s. The Telecommunications Industry Association developed the formal standard based on the design concepts that originated at the Bell Labs.

[11] Dispatch service typically operates over a wide area to many different radios at the same time. For example, a taxicab radio dispatcher will broadcast a request for a pickup to all of its associated drivers at once. The transmission would use one channel per tower, so with a traditional high power site covering a large area, it would use one channel; in a cellular system with many towers covering the same area, the transmission would occupy one channel per cell.

[12] Initially, the FCC required cellular licensees to register each base station.

[13] http://www.fcc.gov/encyclopedia/cellular-service.

After pressure from the Justice Department and state regulators—the latter through the National Association of Regulatory Utility Commissioners (NARUC)—and evidence from two experimental systems in Chicago and Baltimore, in 1981 the FCC decided to award two 20 MHz licenses in each area: one to an incumbent wireline telephone company and one to a non-wireline company.[14]

3.1.5 License Assignment Methods: Comparative Hearings then Lotteries

The FCC divided the country into 734 Cellular Market Areas (CMAs). In each area, only the wireline telephone company or companies that operated in that area were eligible to apply for the "B" block license. The other 20 MHz license was available only to non-wireline companies. The FCC awarded the two cellular licenses available in each area in three different waves: the top 30 markets by comparative hearing when there were mutually exclusive applications, with encouragement of settlement.[15] In the second wave, markets 31–90, applications were submitted under the premise they would undergo comparative hearings.

But, in 1981 Congress passed legislation that permitted a lottery be used to select among mutually exclusive applications, and in 1984 the FCC awarded licenses in markets 31–90 by lottery. Once it was known that lotteries would be used to select winners, "application mills" created inexpensive standard applications and the FCC received over 300,000 applications for licenses that covered the remaining 644 geographic areas.[16] It was not until 1985 that the FCC completed the awarding of the licenses in the top 30 markets and several years later that the FCC held the last lottery for initial cellular licenses.

The ability of winners to resell the licenses somewhat mitigated the inefficiencies that were likely to be associated with the initial assignment by comparative hearings or lottery. For example, secondary markets allowed for the transfer of a license that had been awarded to an inefficient, but lucky lottery winner to a more efficient operator and allowed for geographic aggregation of licenses that had been awarded by lottery or comparative hearing to separate entities. However, secondary market transactions to correct these problems can involve significant time and high transactions costs.[17]

Because the FCC set aside one license for wireline telephone companies, most of which were the Regional Bell Operating Companies, the number of owners of the wireline "B" block licenses was relatively small so efficient geographic aggregation was easier to achieve. On the non-wireline "A" block side, there were a large number of winners, so each winner likely did not have the geographic scope to operate an efficient business. Craig McCaw, among others, saw the opportunity to consolidate

[14] FCC (1982).

[15] In many cases there was only a single wireline telephone company that was eligible for a B block license. But in some cases more than one telephone company provided wireline service within the footprint of a cellular license area, so there could be mutually exclusive applications.

[16] For more discussion of the process, see Kwerel and Felker (1985) and Rosston (1994).

[17] Acquisitions of assets that include spectrum licenses need to be approved by the FCC for "transfer of control" through a public proceeding. In such proceedings, other parties have a chance to comment and exert pressure on the Commission to hamper any deals and impose conditions.

the business and purchased licenses from a large number of lottery winners to put together a large wireless business.

3.2 Personal Communications Services (PCS)

3.2.1 Higher Valued Use: Emerging Digital Wireless and Increased Wireless Competition

In 1989 the FCC began a proceeding to repurpose spectrum from fixed point-to-point use to wireless. The development of digital cellular technology promised opportunities for new devices and services that would increase demand for spectrum. More wireless spectrum would also open a path for additional competitors in the cellular market. The FCC considered several bands for reallocation, including spectrum that was being used for point-to-point systems that the FCC felt could be relocated to other, mostly higher frequencies. Ultimately, the FCC identified 140 MHz of spectrum in the 1.8 GHz band that became known as the Broadband Personal Communications Service band. The FCC allocated 120 MHz of paired Broadband PCS spectrum for licensed use and 20 MHz for unlicensed use.

3.2.2 Clearing Incumbents: Relocation Initially Voluntary then Mandatory with Compensation by New Licensees

The 1.8 GHz band had been used for point-to-point microwave services by a variety of public and private entities. To clear the spectrum, the FCC set up a framework to relocate the microwave systems to different spectrum. The process mandated that the Broadband PCS license winners needed to pay the relocation costs.[18]

Because not all systems could be relocated in a single day, or with the flip of a switch or change in a software code, the FCC gave non-public safety incumbents a three-year window, at the end of which the PCS licensees could force the incumbent systems to move with compensation for costs. However, the Commission also established a system where the two parties could agree to an earlier move. With the backstop of mandated relocation for cost, the two parties could agree to some additional payment or better service in exchange for an earlier move. Since the protection of particular microwave incumbents would often affect two or more PCS licensees, the FCC also adopted rules for the mandatory sharing of clearing costs by all PCS licensees that benefited from such clearing. This corrected a "free rider" problem that could have potentially delayed the relocation process.

3.2.3 Flexibility: Voluntary Standards and Minimum Technical Rules to Control Interference Become the Default Approach for Wireless Bands

The FCC adopted a very flexible, market-based approach for Broadband PCS: Licensees were given service flexibility and technical flexibility, and they also had wide

[18] For a fuller discussion, see Cramton et al. (1998).

latitude about geographic coverage and implementation through relatively lenient (at the time) build-out requirements. Broadband PCS licenses were permitted to provide virtually any service except broadcast radio and TV and satellite service.[19]

To provide maximum flexibility in system design, the FCC minimized technical rules, consisting only of those that were believed to be necessary to control interference: in-band and out-of-band power limits and broadly defined permissible classes of transmitters (fixed, mobile, and base). Consistent with this flexible approach, the FCC decided not to specify a mandatory PCS technology standard, which was unlike what it had done earlier in the cellular bands.

At the time the FCC was promulgating the Broadband PCS rules, Europe had moved forward with its second allocation of spectrum for mobile wireless service and mandated that providers use "GSM" technology, a European standard. Several parties argued that the FCC should also adopt a technical standard for PCS. Motorola argued that it would be much better for the market if the FCC adopted a standard because then equipment manufacturers could realize economies of scale and equipment prices would be lower. In addition, it argued that a government-mandated standard would facilitate consumer roaming internationally and also facilitate switching providers.

In spite of these arguments, the FCC decided that it would be better to let the operators decide what technology they should implement. If the FCC had adopted a standard, service might have been delayed substantially, and the FCC likely would have missed the congressional deadlines. Moreover, system operators should be able to internalize the tradeoffs between economies of scale and roaming. If the economies of scale were so large, or if large numbers of customers wanted to roam, then operators would want to adopt a common standard (Farrell and Topper 1998).

At the time, GSM was one of the three cellular technologies available. TDMA was also in the marketplace, and a new technology— CDMA—was just beginning to show promise. Instead of deciding on the fate of PCS technology, the FCC let operators decide. Several operators initially decided on TDMA and later switched to GSM; others picked CDMA. Ultimately, consumers had to switch handsets to switch providers if the providers adopted different technology, but the up-front switching costs were generally low until smartphones came along. Many providers offered "free" cell phones with the cost paid through higher monthly fees that were tied to 1-year or 2-years contracts.

3.2.4 Competition Policy: Ending the Cellular Duopoly

When the FCC allocated spectrum for Broadband PCS, there were two cellular providers in each geographic area. The FCC's initial proposal for PCS emphasized new low-power services and technologies that would be different from cellular.[20] However, the Commission ultimately opted for a more pro-competitive approach and structured PCS rules to match those of cellular, including comparable power levels.

[19] FCC Rules: "**§ 24.3 Permissible communications.** PCS licensees may provide any mobile communications service on their assigned spectrum. Fixed services may be provided on a co-primary basis with mobile operations. Broadcasting as defined in the Communications Act is prohibited."

[20] See, FCC (1992).

In addition, the FCC adopted rules that effectively prevented the two cellular incumbents from acquiring any of the three large PCS licenses in the same geographic area, and thus ensured new entry.[21] These ownership restrictions were implemented to provide clarity in the auction rules for PCS licenses, as discussed in the next section.

To avoid uncertainty for bidders about whether they would be required to divest licenses acquired in an auction because of competition concerns by regulators, prior to the auctions the FCC established clear rules on permissible PCS spectrum holdings in each license area.[22] In contrast, under *ex post* review of license acquisition, a bidder might hold back from bidding if it was uncertain to pass such review. A bidder might also try to buy more than it might otherwise be allowed to acquire if it assumed that *ex post* rejection would be harder for the FCC if it had to refund auction money and/or re-run the auction and delay service.

In addition, *ex post* review could impede the ability of bidders to assemble efficient packages of licenses in a simultaneous auction. If bidders were required to divest one or more of their licenses acquired in the auction, their remaining licenses might be unprofitable, and it would be too late to pursue a backup strategy in the auction. At the same time, other bidders who might have acquired the subsequently divested licenses as part of a different bidding strategy would be less able to do so after the auction closed.

3.2.5 License Assignment Method: First Major Use of Auctions; A Set-Aside for Designated Entities

With the passage of the Omnibus Budget Reconciliation Act of 1993 ("OBRA '93"), Congress gave the FCC auction authority and required the FCC to auction licenses in the PCS band quickly. Developing efficient auction rules was a new and major undertaking for the FCC. After much study and with the advice and assistance of outside auction experts, the FCC settled on a novel auction design called the Simultaneous Multiple Round (SMR) auction.

In an SMR auction all licenses in the auction are open for bids until there are no bids on any licenses. The SMR design allows bidders to shift bids among licenses that are substitutes as relative prices change and facilitates aggregating licenses that are complements. The auction process allowed the FCC to award spectrum licenses quickly and directly to the parties that valued the spectrum most highly, and thereby avoided lengthy delays and secondary market transaction costs.[23]

The SMR format was first tested successfully with the auction of the Narrowband PCS licenses and then the auction of the much more valuable Broadband PCS licenses. The FCC divided the 120 MHz of Broadband PCS spectrum into three 30 MHz blocks and three 10 MHz blocks. Using the SMR auction design, the FCC auctioned two of

21 FCC (1994). The FCC instituted a CMRS spectrum cap of 45 MHz at the time that prevented a cellular company, with 25 MHz, from acquiring a 30 MHz PCS license because the combination would put it over the cap. However, the cap did not prevent cellular companies from buying two 10 MHz licenses in the same area, or from buying a 30 MHz license in an adjacent area (or any other area).

22 *Id.*

23 See for example, McMillan (1995), Kwerel and Rosston (2000), Cramton (2002), and Milgrom (2011).

the 30 MHz PCS blocks in late 1994 and the third one in late 1995, and also the three 10 MHz blocks in 1996–1997.

The first two 30 MHz blocks brought in $7.7 billion to the U.S. Treasury. The third 30 MHz block brought in bids of $10 billion, but much of that money was never paid to the Treasury. In part to satisfy Section 309(j) of the OBRA '93, these licenses had been set aside for small entities that were given generous installment payment terms and then defaulted on most licenses.[24]

3.3 Satellite Digital Audio Radio Service (SDARS) and Wireless Communication Service (WCS)

3.3.1 Higher Valued Uses: Satellite Radio and Mobile Wireless

In June 1995, the Commission proposed to reallocate the 2,305–2,360 MHz band (a total of 55 MHz) for SDARS on a primary basis.[25] Before that, the band had been allocated for radiolocation and fixed and mobile terrestrial services and was used primarily in the U.S. for Aeronautical Mobile Telemetry (AMT) systems.

In 1996 Congress adopted legislation that required that 30 MHz of the proposed SDARS spectrum (15 MHz at each end of the 55 MHz band) be auctioned instead for flexible use, which left 25 MHz in the middle for SDARS.[26] On November 8, 1996, the FCC proposed licensing rules for the 30 MHz flexible-use blocks that were modeled after the rules for PCS but with a much stricter out-of-band emission limit that was designed to protect SDARS from interference.[27] It proposed to create a new service called the Wireless Communications Service (WCS).

3.3.2 Clearing Incumbents

To accommodate SDARS and WCS, the FCC reduced the AMT allocation in this band in the U.S. to secondary status, which allowed any existing AMT (mostly flight-test) systems to continue without protection until the band was deployed for the new allocation. Costs, if any, that were associated with the removal of existing AMT systems from this spectrum were absorbed by the users of those systems. Given the long time that

[24] See Kwerel and Rosston (2000).

[25] "Satellite CD Radio, Inc. (CD Radio) initiated this proceeding in 1990 by filing a petition to allocate spectrum for satellite DARS and an application to provide the service. In February 1992, the World Administrative Radio Conference (WARC-92) adopted international frequency allocations for Broadcasting Satellite Service (BSS) (sound)(the international term for satellite DARS). Internationally, this band was also allocated on a primary basis to radiolocation services and fixed and mobile terrestrial services. In November 1992, the Commission established a proceeding to allocate satellite DARS spectrum domestically and announced a December 15, 1992 cut-off date for satellite DARS license applications to be considered with CD Radio's. Of the six license applicants that filed before the cut-off; four remain: CD Radio, Primosphere Limited Partnership (Primosphere), Digital Satellite Broadcasting Corporation (DSBC) and American Mobile Radio Corporation..." Excerpt from FCC *Report and Order, Memorandum Opinion and Order and Further Notice of Proposed Rulemaking*, March 3, 1997.

[26] Omnibus Consolidated Appropriations Act, 1997, P.L. 104–208, 110 Stat. 3009 (1996).

[27] WCS NPRM: FCC 96–441, adopted November 8, 1996; 11 FCC Rcd 21713 (1996).

was allowed for clearing, the cost impact on incumbents was small. AMT continues to be a primary use of the band immediately above the combined SDARS/WCS band, and the protection of those systems requires WCS to abide by additional technical restrictions and coordination requirements, although not as onerous as the restrictions that are needed to protect SDARS.

3.3.3 Flexibility: SDARS not Flexible; WCS Highly Flexible but Subject to Strict Out-Of-Band Emission (OOBE) Limits that, as Practical Matter, Reduced Flexibility to Zero

WCS providers had flexibility that was similar to Broadband PCS in their service and technology choices.[28] However, the Commission imposed very stringent OOBE limits on the WCS providers to protect sensitive receivers used by the SDARS licensees whose spectrum was in the middle of the WCS blocks. These strict emission requirements limited substantially the ability of WCS licensees to provide valuable service. The limits were known in advance of the WCS auction, which is a major reason that it raised only $14 million for 30 MHz of paired spectrum whereas the PCS licenses of comparable size sold for nearly $4 billion, which is a factor of more than 20.[29]

The SDARS licenses did not have any of the same flexibility that was granted to WCS. The FCC mandated that these licenses be used for satellite transmission, and that the product be radio service. Subsequently, the FCC granted some waivers to allow terrestrial repeaters so that the radio service could be heard in areas such as tunnels.

3.3.4 Competition Policy: New Satellite Competitor to Terrestrial AM/FM Broadcasting

The potential adverse effect of SDARS competition on terrestrial AM/FM broadcasting was a contentious issue throughout the SDARS proceeding. However, the FCC decided that the competitive threat would be minimal and ultimately moved forward with SDARS, which is now more commonly known as "satellite radio." In 1997 the FCC auctioned the SDARS spectrum in two licenses of 12.5 MHz each and brought in $173 million.

In the case of WCS, competition policy never became an issue, possibly because most concerns about competition in the cellular market had been recently addressed with the new PCS spectrum. The creation of WCS was mostly about the additional spectrum availability and the auction revenue that it would raise, which unfortunately failed to materialize because of the stringent technical restrictions that were imposed

[28] WCS flexibility also allows the provision of SDARS service on the WCS frequency blocks 2,310–2,320 and 2,345–2,360 MHz. FCC Rules, Section 27.2(c).

[29] The FCC has recently revised the WCS technical rules to implement an agreement that was privately negotiated between the consolidated SDARS licensee (Sirius) and AT&T, which has acquired much of the WCS licenses. The new rules should finally allow deployment and use of the WCS spectrum while preventing interference between the WCS and SDARS bands. See FCC (2012).

to protect SDARS. As was mentioned above, the 30 MHz of WCS spectrum sold for a total of $14 million nationwide.[30]

3.3.5 Lessons from DARS/WCS

The FCC's mandate of satellite radio service and the attendant protection limited the capabilities of the WCS licensees and had a large impact on the value of that spectrum. 55 MHz of prime spectrum (25 MHz for SDARS and 30 MHz for WCS) sold for less than $200 million, which was a small fraction of the value of wireless spectrum that was not subject to stringent power limits.

Arguably, SDARS and WCS spectrum should have been sold together and without the stringent and value-diminishing power limits the FCC imposed to protect SDARS. SDARS bidders might then have purchased the WCS spectrum and used it to expand the capacity of their SDARS systems or used some for terrestrial mobile services with whatever power limits they wanted to protect their SDARS receivers, or for an internal guard band.[31] They would then have faced the full opportunity cost of the spectrum that was needed to accommodate SDARS and would have had an incentive to use the spectrum for maximum value, efficiently trading off the value of WCS spectrum against the value of protecting SDARS.

Given those choices, licensees might have decided that it was less costly to make the SDARS system more robust against interference— e.g., by using better receivers— so that some or all of the WCS spectrum could be used for wireless under normal power limits. It is also possible that SDARS would not have been deployed at all if the SDARS blocks were also flexibly allocated so that all spectrum costs were fully internalized, or SDARS would have deployed in higher, less costly frequencies.

SDARS has proven its value in the marketplace, although at a substantial opportunity cost in terms of spectrum that it uses as well as spectrum that it impairs in adjacent bands.

3.4 Digital TV (DTV) Transition and the Second Repurposing of Television Spectrum to Land Mobile Wireless (the 700 MHz band)

3.4.1 Higher Valued Use: Rapid Wireless Growth and the "Digital Dividend"

The demand for cellular service grew rapidly with the introduction of digital technology, smart phones, and lower prices that were driven by competition. It was clear that additional spectrum wouldbe needed to accommodate this growth. At the same time,

[30] The value of WCS spectrum appears to have substantially increased, as evident in the August 02, 2012, announcement by ATT to purchase WCS license holder NextWave for a total of $ 600 million: http://www.att.com/gen/press-room?pid=23161&cdvn=news&newsarticleid=34976&mapcode=.

[31] Auctioning a single nationwide license for the WCS spectrum would have internalized all of these cost and value tradeoffs, and arguably would have led to more efficient and valuable overall use of this spectrum. However, auctioning a nationwide license would likely have met with opposition from smaller, regional entities that sought smaller licenses.

demand for over-the-air television was decreasing, with most viewers' receiving local broadcast stations over cable. The introduction of more robust digital TV receivers also reduced the channel separations needed to control interference.

When the FCC first licensed analog broadcast television stations, it assigned each broadcaster one 6 MHz channel and mandated that it broadcast a National Television System Committee (NTSC) analog signal. To limit interference the FCC mandated the maximum power level of the transmission and did not assign licenses in the same area on the same channel or on adjacent or certain other "taboo" channels to prevent interference.

In 1987 the FCC began the "Advanced Television" proceeding.[32] With the improvement in digital technology in the early 1990s, the FCC found that broadcasters could operate with less protection, and the FCC was therefore able to make some of the TV spectrum available for other uses while at the same time improving the picture quality of over-the-air television. Also, the decrease in the value of over-the-air TV broadcasting and the increase in the value of the alternative use, mobile wireless, made the transfer of spectrum from one use to the other much more socially valuable.

In 1996 Congress mandated that the FCC "loan" a second channel to all television broadcasters so that they could begin to transmit digital television signals.[33] When enough households had adopted digital technology, the broadcasters would cease analog operation and return the analog channels to the FCC.

Accommodating the same number of TV stations on fewer channels was possible because the new digital stations were more robust against interference. All of the existing stations could thus be "repacked" down to the lower channels, which allowed the upper channels (52–69) to be repurposed for wireless (the 700 MHz band), thereby creating what is often called the "digital dividend."

3.4.2 Clearing Incumbents: Mandatory Repacking of TV Stations Without Compensation

As in the initial transfer of broadcast spectrum to the cellular and other land mobile radio systems in the early 1970s, no existing TV stations were required to go dark as a result of the DTV transition. Instead all stations were relocated to lower channels. The cost of switching to digital and moving to lower channels were not reimbursed. However, a long transition time was provided, and the government subsidized the purchase of converter boxes for consumers to allow digital over-the-air reception for analog televisions.

[32] FCC (1987). The first high definition television in the 1980s in Japan was analog, and initially the FCC considered mandating analog technology to keep pace with the Japanese during this time period.

[33] Telecommunications Act of 1996, Pub. L. No. 104-104, 110 Stat. 56 (codified at scattered sections of 47 U.S.C.).

3.4.3 License Assignment Method and Competition Policy

The FCC auctioned some of the spectrum in the 700 MHz band in 2005, prior to the DTV transition, when it was not clear when the conditions that Congress established for the broadcasters to vacate the spectrum would be met. In early 2008, after Congress had set the "date certain" of 2009 for broadcasters to discontinue analog broadcasting, the FCC auctioned the remaining 700 MHz spectrum for flexible wireless use.[34]

In the 2008 700 MHz auction, the FCC set aside a nationwide 10 MHz block of paired spectrum—the D block—to provide commercial wireless service, but with the additional requirement that the winning bidder enter into a "Public/Private Partnership" with the nationwide "Public Safety Broadband Licensee" to also provide interoperable broadband public safety service on a priority basis.

The thought was that commercial and public safety spectrum uses are in many ways complementary and that combining them on a single system with priority access for public safety would be more efficient overall than building a separate, dedicated public safety system. Essentially, the bidders would have paid for the right to negotiate the details of such a system with public safety.

Although there was one bid on the D block during the auction, that bid was below the reserve price, so the license was not sold. Congress subsequently reallocated the D Block to Public Safety and appropriated funds to be derived from future FCC auctions for construction of a nationwide, dedicated system.[35]

In addition, the FCC mandated an "open access" provision on the C block—22 MHz of spectrum—if the price exceeded $4.6 billion. Ultimately, the C block sold for just over this amount so the requirements continue with that license. Bazelon (2009) and others have argued that the combination of different regulatory mandates and different license areas for different blocks along with auction design features that made it difficult to switch bidding among blocks resulted in a substantial reduction in auction revenue.

3.5 Advanced Wireless Service (AWS): Repurposing Government Spectrum

In 2006, the FCC auctioned "Advanced Wireless Service" ("AWS") spectrum in the 1.7 GHz band paired with spectrum in the 2.1 GHz band. Prior to the auction, the federal government operated in the 1.7 GHz band.

The 1.7 GHz band was used by federal agencies and covered by a Congressional mandate that requires that auction proceeds fund the estimated relocation costs of incumbent federal entities. The 2.1 GHz band was used by fixed microwave services (including state and local governmental public safety services) and the Broadband Radio Service ("BRS"). The Commission adopted procedures by which new AWS

[34] The end of the digital transition was established as part of the Deficit Reduction Act of 2005, which Congress passed in February 2006. See Section 3002 (Title III of this Act comprises the Digital Television Transition and Public Safety Act of 2005, which, amended 47 USC 309. The legislation set the date at Feb. 17 2009. In early February of 2009 Congress delayed the date to June 12, 2009. See http://www.ntia.doc.gov/legacy/otiahome/dtv/PL_109_171_TitleIII.pdf.

[35] Middle Class Tax Relief and Job Creation Act of 2012, Section 6101.

licensees may relocate incumbent BRS and fixed microwave service operations in a manner similar to that developed for clearing the PCS band.

Like the Broadband PCS relocation, for the most part, the new licensees needed to pay for equivalent service for the users of those bands. However, in part because of disputes about the amount of the relocation costs and little or no gain to moving for federal agencies, the complete relocation out of the band took longer than the initial timeline.

3.6 Lessons from Government-Mandated Transitions

The FCC played different roles in these five transition scenarios. In cellular and SDARS, it mandated that the reallocated spectrum be used for a new, unproven service. The FCC-mandated reallocation of spectrum from broadcast television to cellular appears to have been very socially beneficial, although the lengthy period required also had costs.

In the SDARS/WCS case, greater value likely would have been achieved by instead arranging a flexible allocation that would have permitted SDARS but not foreclosed other potentially more valuable uses such as additional flexible terrestrial wireless service. In the 700 MHz band, the FCC coordinated the digital television transition that repacked incumbent television broadcasters into the lower part of the UHF band, which made 108 MHz of spectrum available for flexible mobile services. Achieving this level of coordination and integration without FCC involvement would have been very difficult.

In the Broadband PCS case the FCC established a framework in which new flexible wireless licensees could require microwave incumbents to clear by a fixed date if compensated according to a schedule established by the FCC, and could negotiate a premium for clearing before that date. This process relied heavily on private negotiation that was buttressed in critical ways by FCC rules to solve bargaining problems.

Finally, in AWS, the FCC and NTIA worked together to develop a workable mechanism to move government users into different spectrum bands. While the process ultimately has proven successful, there have been complaints about the time that it takes for government users to relocate.[36]

4 Privately-Initiated Transitions

4.1 Specialized Mobile Radio (SMR) to FleetCall (and Nextel)

At the same time that the FCC allocated spectrum for the new cellular service, it also allocated nearby spectrum for private radio services such as "industrial and land

36 "For example, the AWS-1 spectrum we hold was utilized by certain governmental users, many of whom are required over time to relocate from the AWS-1 spectrum. However, in some cases, not all incumbent users have relocated or are obligated to relocate and, in other cases, may not be obligated to relocate for some period of time, with varying time frames for relocation." T-Mobile 2012 Annual Report.

transportation," "radiolocation," "public safety."[37] It also created a new multi-channel category called "specialized mobile radio" or "SMR". Multiple channel systems provided "trunking" efficiency where more users could be accommodated on a given number of channels with less congestion.

All of these private radio systems initially operated as "dispatch" systems with the ability to simultaneously address a fleet of cars or trucks using a single high power tower covering a large geographic area. The multi-channel SMR category allowed commercial operators to build larger, more efficient shared systems and sell dispatch services to companies that were not large enough to justify their own systems.

4.1.1 License Assignment

Initially, the FCC mandated either "conventional" or "trunked" technology for the private land mobile 800 MHz licenses.[38] SMR operators were allowed to profit from their service, whereas other private land mobile licensees were not.[39] SMR operators used their profit incentives to provide more efficient dispatch services by aggregating channels into larger trunked systems, paying other operators to relocate transmitters to improve coverage, and charging different amounts for use of spectrum in different areas, and charging different amounts for interconnected calls that allowed conversations with landline telephones.

The FCC awarded SMR licenses on a first-come, first served basis. The FCC opened filing windows, and applicants filed for specific sites. If there was not another conflicting assignment, then that license was granted. Subsequent applications then had to protect that licensee from interference.

4.1.2 Use of the FCC Process to Obtain Flexibility

Morgan O'Brien, an FCC attorney, understood that the spectrum allocated for SMR was adjacent to the spectrum allocated for interconnected cellular use. Essentially the SMR spectrum was similar, and the restrictions on it were artificial; the profit motive was the same, and the ability to provide similar services was a technical issue. He left the FCC and in 1987 created a company called FleetCall, which was renamed Nextel in 1993, and with other SMR operators joined in repurposing some of the private land mobile radio allocation.

FleetCall's first step was to obtain a waiver of the FCC rules so that it could install cellular architecture rather than the high-power towers that were originally authorized. That "FleetCall waiver" required the FCC to move from site-specific licensing to

[37] Taxicab radio was a specific subcategory of land transportation, and the FCC reserved specific channels for such specific services. For a further discussion of the SMR systems, see Rosston (1994).

[38] With "conventional" technology, two users would have to manually select a channel and wait for a clearing in traffic to make their transmission. "Trunked" technology allows users automatically to select a channel over a group of channels.

[39] To be clear, equipment providers and network operators who provided services to licensees were allowed to profit.

area licensing, so as to allow the licensees to combine their SMR licenses into area licenses.

Once it obtained the approval for area licenses and cellular architecture, the company (then renamed Nextel) worked with Motorola to develop a technology that was similar to the cellular systems. However, because of the balkanized channelization in the private mobile bands, Nextel's technology had substantial differences. Interleaved between the SMR channels were high-power channels for other private land mobile radio licensees, such as public safety, that had not adopted the cellular architecture. As a result, the iDEN technology that Motorola developed had to account for disparate architectures on adjacent channels.

4.1.3 Clearing

Initially, repurposing SMR spectrum was done without FCC mandates. SMR consolidators started by purchasing SMR licenses and incorporating them into trunked systems and later into iDEN systems. In addition, they acquired licenses that originally had been designated for "business" users and converted them to SMR licenses through the FCC process. Then FleetCall sought and eventually received its waiver from the FCC, which allowed it to clear high power sites and deploy a low-power cellular system.

Later, the FCC auctioned "overlay" licenses for the SMR spectrum to provide for the ability to convert site-specific licenses into wide area systems and to license fully entire geographic areas rather than having "white spaces" with no licensee.[40]

4.1.4 Interference

The interleaving of spectrum used by systems with cellular and traditional land mobile architectures led to interference. Unlike in a conventional land mobile system, base transmitters in a cellular system are numerous and close to the ground. Conventional mobile receivers on the interleaved non-cellular channels were designed to tolerate only relatively weak adjacent channel signals from a single, distant base station but not the much stronger signal from a nearby cellular base station. Interference occurred particularly when a conventional land mobile handset was far from its tower but near a Nextel cell site. It could not reject the stronger adjacent channel Nextel signal in favor of the weak signal from the distant tower of its own system.

In this case, both operators were providing service within the terms of their licenses, but there was interference. In general, when two high-power systems were operating on adjacent channels, the same problem could occur, but there are fewer towers for the high-power transmitters so the issue is less common, and frequently the high-power transmitters are co-located so the problem would not occur.

In this case, the FCC worked with Nextel and the Public Safety community to resolve the interference. They negotiated a rebanding plan that consolidated Nextel

[40] The FCC held Auction 16 in late 1997 for the SMR overlay licenses. See http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=16.

and public safety spectrum in different parts of the band. Nextel was required to pay public safety entities for relocation costs.[41]

4.2 2,500–2,690 MHz: The Long, Circuitous Path from Educational Use to Commercial Wireless

4.2.1 Instructional Television Fixed Service (ITFS) and Multipoint Distribution Service (MDS)

The FCC initially set aside the 2,500–2,690 MHz band in the early 1960s exclusively for use by educational institutions. Technical rules required a one-way, point-to-multipoint architecture similar to TV and based on the same 6 MHz channeling and analog TV transmission technology that was used in the UHF and VHF TV broadcasting bands.

The 190 MHz that was available in the band yielded 31 one-way 6 MHz TV channels plus some spectrum at the upper end of the band to allow for transmission in the reverse direction (e.g., from students to teacher). To simplify the management of interference, the 6 MHz channels were organized in non-contiguous, interleaved groups (Groups A through G) of 4 channels each, plus one group of 3 channels (Group H). Channel groups were licensed on a site-by-site basis.

For a variety of reasons, educational use of the ITFS band did not grow as expected. Equipment capable of operating at these high frequencies was limited and expensive. Signal blockage by hills and even trees made reliable coverage difficult. More fundamentally, demand from the educational community didn't materialize at the magnitude that had been expected. The largest licensee was the Catholic Archdiocese.

In a series of rulemaking decisions, the FCC gradually relaxed the "education only" requirement of the band to allow greater commercial access. Initially, the FCC allowed educational licensees to lease some portion of their system capacities for commercial use. The Commission increased the allowance for commercial use several times, but never eliminated the educational requirement. Later, the Commission repurposed the 3 channel H group for a new commercial Multipoint Distribution Service, while still allowing limited leasing of the educational channels.

Later, the FCC increased the number of MDS channels and added the term "Multichannel" to MDS, calling it MMDS. The expected commercial use at that time shifted toward a subscription-based multichannel TV service to consumers, either as a competitor to cable or in areas not served by cable. Despite these continued adjustments, significant commercial use of this spectrum still failed to materialize.

4.2.2 Transition to Educational Broadband Service (EBS) and Broadband Radio Service (BRS)

Commercial licensees in the 2,600 MHz band initiated the reallocation of spectrum from Multipoint Distribution Service (MDS) to Broadband Radio Service (BRS) and

41 FCC (2004). The history is summarized in pp. 13–14, 36–46.

from Instructional Television Fixed Service (ITFS) to Educational Broadband Service (EBS). They saw the opportunity to create higher-value licenses with a cellular architecture than was the service that was provided with existing higher-power site licenses.

The licensees proposed to create two blocks that were suitable for systems with a cellular architecture separated by a block that was suitable for the high-power site licenses of the legacy services. The users developed a complex way of exchanging their existing rights (to broadcast from a particular site on specific frequencies) to a new set of rights (a mixture of paired low-power area licenses and high power site licenses with the same total amount of spectrum as the initial licenses).

Since the spectrum restructuring could not be achieved unless all the licensees in an area agreed to swap their licenses, the coalition that proposed the reallocation enlisted the FCC to require that all parties in an area participate when requested by a party that was willing to pay for relocation costs.

The transition process took several years to implement. The difficult coordination problem of simultaneously moving many parties without holdouts was achieved because the control (ownership and long-term leases) of this spectrum was highly concentrated and the FCC mandated restructuring when requested by parties that were willing to pay the moving costs.

4.3 Satellite Flexibility: DISH and LightSquared

The success of flexibly licensed CMRS—such as cellular, PCS, and AWS—along with the ability to take a relatively underdeveloped service such as SMR and convert it to a very valuable service, did not go unnoticed. The SDARS allocation was only a small part of the spectrum that the FCC allocated for satellite services. The other satellite services shared one important characteristic with SDARS: satellite services were not necessarily the highest value use of the spectrum. As a result, satellite licensees petitioned the FCC, not just for the rights to use terrestrial repeaters to cover tunnels and other hard to reach areas with satellites, but essentially to convert their satellite authorizations to much more valuable terrestrial operations.

There were three major issues with the conversions: First, was it technically possible to use the spectrum for terrestrial operation and not cause interference to other users in adjacent bands? Second, was it fair to let satellite licensees that had acquired their licenses without an auction to obtain a windfall gain from converting use? Finally, there would be objections from other spectrum users who did not want to face additional competition.

4.3.1 Initial Rights and Responsibilities Matter

The FCC authorized the transition for some satellite companies despite objections. LightSquared and DISH network each received initial authority from the FCC to begin terrestrial operations. However, LightSquared encountered substantial opposition from the GPS community that operates on the adjacent band.

If LightSquared were to operate within the terms of its license, it could cause substantial interference to GPS receivers that were not built to reject terrestrial signals in the adjacent band from nearby transmitters (similar to the 800 MHz Nextel-Public Safety problem discussed above). At the time that the GPS receivers were designed and built, only relatively weak signals from distant satellites were present in the adjacent band.

There is a question from an efficiency and equity perspective as to what interference standards LightSquared should be required to meet. The GPS systems have been operating for 10 years, and there are millions of GPS devices that might be harmed from terrestrial operation by LightSquared. One could also argue that the GPS receivers should have had no expectation that the operation on the adjacent band would continue to be satellite and that they should have built more robust receivers. At this point in time, the FCC has prevented LightSquared from using terrestrial transmitters on its licensed frequencies.

4.4 Lessons from Privately-Initiated Reallocations

In the three case studies of privately-initiated transactions the petitioners for a reallocation already held most of the spectrum for which they sought reallocation, enabling them to capture much of the gain from a reallocation. The internalization of the gain provided a strong incentive to seek the reallocation. It also provided leverage to help overcome bargaining issues in clearing incumbents.

The private incentive for reallocation was weaker in the cases discussed earlier in the section on government-mandated reallocations. In those cases the share of rents that firms could capture from a reallocation varied with the extent of competition for acquiring the newly reallocated spectrum. The local exchange carriers faced little competition for the cellular "B" block that the FCC set aside for them and could have captured a substantial share of the rents, absent rate regulation. In contrast, mobile operators that bid for the A and B block Broadband PCS licenses faced significant competition in the FCC auction, which limited their ability to capture rents from the reallocation.

In the three case studies of privately-initiated transactions the licensees were able to consolidate their ownership of spectrum rights in advance of petitioning the FCC for expanded rights. The FCC had to play a role in all three of these transitions because it had not initially allocated complete license rights: Licensees were limited in service scope (LightSquared and DISH), geographic scope (SMR), and two-way capabilities (BRS/EBS). Because the repurposing of this spectrum promised greater benefits to the public and the economy, the FCC granted additional flexibility to these parties despite the potential for a windfall gain.

5 Conclusion

Over the FCC's 80-year history, repurposing spectrum has become increasingly necessary as new uses have emerged and existing uses expanded or contracted with advancing technology and changing consumer preferences. The early administratively determined spectrum allocations, while likely efficient at the time of adoption became inefficient. The need for a more dynamically efficient allocation process has become more important over time as radio technology and its applications have become more powerful and central to modern society. In response, the repurposing process itself has evolved from an entirely administrative process to one that increasingly incorporates market mechanisms.

As the entire usable spectrum becomes more crowded it becomes more difficult to clear incumbents administratively by providing them with free replacement spectrum in another band. Increasingly it will be efficient for low-value incumbent uses to exit the spectrum entirely in order to make spectrum available for higher valued uses. In some cases where spectrum is already flexibly and exhaustively allocated, markets and private trading can be an efficient way to do this without a significant role for the FCC.

In other cases the FCC is likely to play an important role future. For example, the FCC has proposed to implement a two-sided auction to use market forces combined with government mandates to facilitate the movement of spectrum from broadcasting to a more flexible use if there is sufficient demand. The lessons from past reallocations of spectrum show that the government should endeavor to have the new allocations flexibly licensed so that changes in use can be more dynamic, and the government should play a role to prevent a small number of private parties from frustrating the goals of more efficient, competitive use of the radiofrequency.

Finally, voluntary trading may not be effective in repurposing spectrum used by the federal government and non-federal government agencies (e.g., public safety) that generally are not able to retain revenues from relinquishing spectrum rights and use the revenue to further their missions in other ways. Relocation by fiat may continue to be necessary in those bands, or, possibly, new uses can be accommodated through more intense band sharing using smart radios, such as those that are being developed in the 3.5 GHz band.

References

Bazelon, C. (2009). Too many goals: Problems with the 700 MHz auction. *Information Economics and Policy*, *21*(2), 115–127.

Blumberg, S., & Luke, J. (2013). Wireless substitution: Early release of estimates from the National Health Interview Survey, July–December 2012. http://www.cdc.gov/nchs/data/nhis/earlyrelease/wireless201306.pdf. Accessed on September 1, 2013.

Coase, R. (1959). The Federal Communications Commission. *Journal of Law and Economics*, *3*, 1–40.

Cramton, P. (2002). Spectrum Auctions. In Cave, M. Majumdar, S. & Vogelsang, I. (Eds.), *Handbook of telecommunications economics* (Chapter 14, pp. 605–639). Amsterdam: Elsevier Science B.V.

Cramton, P., Kwerel, E., & Williams, J. (1998). Efficient relocation of spectrum incumbents. *Journal of Law and Economics*, *41*, 647–675.

DeVany, A., Eckert, R., Meyers, C., Ohara, D., & Scott, R. (1969). A property system for market allocation of the electromagnetic spectrum: A legal-economic-engineering study. *Stanford Law Review*, *21*(6), 1499–1561.

Farrell, J., & Topper, M. (1998). Economic White Paper on National Third Generation Wireless Standards. Cornerstone Research Staff Working paper.

Federal Communications Commission. (1968). Docket 18262, Notice of Inquiry and Notice of Proposed Rulemaking, 22 Fed. Reg. 10807.

Federal Communications Commission. (1982). Docket 18262, report and order, 86 F.C.C. 2nd 469 (1981); modified, 89 F.C.C. 2nd 58 (1982); further modified, 90 F.C.C. 2nd 571.
Federal Communications Commission. (1987). MM Docket No. 87–268 Notice of Inquiry. 2 FCC Rcd 5125.
Federal Communications Commission. (1992). Second report and order, ET Docket No. 92–9, 7 FCC Rcd 6886.
Federal Communications Commission. (1994). Memorandum opinion and order, ET Docket No. 92–9.
Federal Communications Commission. (2004). Improving public safety communications in the 800 MHz band. Fifth report and order, fourth memorandum opinion and order, 19 FCC Rcd. 14,969.
Federal Communications Commission. (2012). Order on reconsideration WT Docket No. 07–293. http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-12-130A1.pdf.
Federal Communications Commission. (2013). Internet access services: Status as of June 30, 2012. Industry Analysis and Technology Division, Wireline Competition Bureau, released May 2013. http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-321076A1.pdf. Accessed on September 1, 2013.
Hazlett, T. (2001). The Wireless Craze, the Unlimited Bandwidth Myth, The Spectrum Auction Faux Pas, and the Punchline to Ronald Coase's 'Big Joke': An Essay on Airwave Allocation Policy. *14 Harvard Journal of Law & Technology* 2, 335–567.
Herzel, L. (1951). Comment, Public Interest and the Market in Color Television Regulation, 18 U. CHI. L. REV. 802 (1951).
Kwerel, E., & Felker, A. (1985). Using auctions to select FCC licensees. Federal Communications Commission OPP Working Paper Series, No. 16.
Kwerel, E., & Rosston, G. (2000). An insiders' view of FCC spectrum auctions. *Journal of Regulatory Economics*, *17*(3), 253–289.
Kwerel, E., & Williams, J. (2002). A proposal for a rapid transition to market allocation of spectrum. Federal Communications Commission OPP Working Paper Series, No. 38.
McMillan, J. (1995). Selling spectrum rights. *Journal of Economic Perspectives*, *8*(3), 145–162.
Milgrom, P. (2011). Critical issues in market design. *Economic Inquiry*, *48*(2), 311–320.
President's Council of Advisors on Science and Technology (PCAST). (2012). Report to the president for realizing the full potential of government-held spectrum to Spur Economic Growth, July http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.
Rosston, G. (1994). An economic analysis of the effects of FCC regulation on land mobile radio. Ph.D. dissertation, Stanford University.
Rosston, G. (2014). The relationship between technological and regulatory change in the communications industry. Forthcoming in Payson, S. (Ed.) Public economics: The Government's Role in American Economics. ABC-LIO Press.
Rosston, G., & Steinberg, J. (1997). Using market-based spectrum policy to promote the public interest. *50 FED. COMM. L.J.*, *87*, pp. 99–103.
Webbink, D. (1980). Frequency spectrum deregulation alternatives. Federal Communications Commission OPP Working Paper Series, No. 2.
White, L. (2001). 'Propertyzing' the electromagnetic spectrum: Why it's important, and how to begin. In Eisenach, J. & May, R. (Eds.), *Communications deregulation and FCC reform: Finishing the job* (Ch 6, pp. 111–144). Boston: Kluwer.