Formal and Informal Governance: The Future of Spectrum is Sharing…But How Do We Do It?

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Abstract Formal spectrum-sharing solutions – i.e., contractual mechanisms intended to incentivize resource sharing and enforced by government agencies – often emerge in contemporary discussions regarding spectrum policy. In this paper we document the variety of *informal* spectrum-sharing practices observed within the current liberalized-licensing regulatory regime. Informal sharing agreements are self-enforcing understandings between autonomous stakeholders to allocate resources in a particular way and can mitigate transaction costs incurred by involving third-party regulatory institutions in internal governance issues. We argue that Elinor Ostrom's theory of polycentricity provides an important framework for understanding how both formal and informal governance practices can be implemented in conjunction with each other to efficiently allocate spectrum resources across different uses.

JEL Codes:

> [T]he norm for spectrum should be sharing, not exclusivity. (President's Council of Advisors on Science and Technology [PCAST]), 2012)

1. Introduction

Spectrum has always been shared. Radio and television stations use the same frequencies in different locations. The spectrum allocation bodies, such as the International Telecommunications Union (ITU), the Federal Communications Commission (FCC) and the National Telecommunications and Information Agency (NTIA) routinely allow multiple uses on the same band. Indeed, the President's Council of Advisors on Science and Technology (PCAST) themselves noted that "the norm for spectrum should be sharing" (PCAST, 2012).

The modern conception of spectrum sharing involves the use of a specific radio frequency bandwidth by multiple entities within a similar geographic area. From an economic perspective, it is not at all a surprising position that spectrum should be shared across multiple uses. As with many other natural resources, spectrum serves as an input for a variety of productive societal services, and resource allocation should consistently flow to uses which are most valuable given current economic conditions and demands. Nevertheless, the wide variety of sharing arrangements we observe in contemporary spectrum bands alternatively highlights that the question of *how* spectrum should be shared across competing uses lacks a clear answer.

Most (if not all) governance arrangements observed in modern societies incorporate some degree of formal contracting. Formal contracts are ex-ante agreements to share resources in particular way and are, very importantly, enforced by an exogenous third party. Typically, this third party is some form of government institution – e.g. in the case of US spectrum governance, the FCC typically takes this role. Formal contracting can be a powerful coordination device for facilitating efficient resource sharing when a third-party can be designated to effectively describe and enforce both property rights and contract terms. In such environments, a long line of economic reasoning dating back to Coase argues that efficient resource allocations can be achieved if parties can costlessly bargain over property rights of the resource. The large modern literature in market design formalizes and extends Coase's insights to describe how resources can be efficiently allocated via formal contracts for a broad array of complex transactional environments. Insights from this literature were used in recent years to design auction mechanisms for reallocating spectrum for certain frequency bands.

Nevertheless, much of observed spectrum sharing is informal in nature. An important example is governance of the amateur radio band, which is currently managed via a combination of informal etiquette practices, volunteer organizations, and very limited FCC involvement. Even spectrum-governance arrangements which rely heavily on formal contracting may still involve some degree of informal coordination. For example, "overlay" sharing arrangements allow a primary spectrum user to negotiate formal spectrum-sharing contracts with designated secondary users. These arrangements allow primary users extensive flexibility in the kinds of spectrum-sharing contracts that can be offered and allow secondary users the ability to opt out and into spectrum usage at their discretion. The ultimate contractual outcome that is reached between a primary and secondary user can thus be alternatively thought of as an informal agreement to choose a particular outcome among a set of alternatives that are permissible in the context of the exogenous formal institution they are jointly operating under. The ubiquity of informal coordination in observed spectrum-sharing practices suggests that a proper regulatory framework for accessing broad allocation decisions across competing spectrum uses should be able to accommodate a continuum of value-creation strategies varying in the degree to which these strategies rely on informal governance instruments as opposed to formal ones.

In this paper, we argue that the theory of polycentricity, pioneered by Elinor Ostrom, provides a powerful framework and policy tool for future spectrum-management decisions as it allows simultaneous consideration of both formal and informal governance institutions. Particularly, we suggest that spectrum policy can be organized on a continuum from Coasean excludability to Ostromian commons governance. Fortunately, an Ostromian perspective does not require a choice – Ostrom's insight was to develop general frameworks for commons, with technology and human factors determining which regime is best. Hence, it generalizes the earlier work in the neoclassical tradition.

Our overarching purpose with this paper is to make the Ostromian insight of commons more prominent as an explanation, and to be clear that these insights are not specifically what Coase and the property rights school predicted. We also want to show that the increase in demand for wireless and the wireless crunch, contrary to what it might seem, necessitates sharing of spectrum, not more emphasis on excludability.

The paper is structured as follows: In Section 2 we provide a brief history of spectrum management in the United States, describing the regime shift from exclusive licensing to liberalized licensing with an emphasis on spectrum sharing. In Section 3 we discuss how informal spectrum sharing has been an integral component of governance in various spectrum bands and describe how the theory of polycentricity can be used to both explain the presence of informal coordination in spectrum sharing and evaluate the effectiveness of current spectrum-sharing alternatives particularly in considering how formal and informal governance instruments interact. In section 4 we provide three specific case studies of spectrum-sharing arrangements which utilize both formal and informal governance components. Section 5 concludes.

2. History of Spectrum Management in the United States

Spectrum has features of a commons in that it is nonexcludable and divisible. It is not divisible like most natural resources, as spectrum does not get used up in the same way as, say, water or fisheries do. It is not at risk of a "tragedy of the commons" as Hardin (1968) understood it, which refers to overconsumption of natural resources and degradation of the global environment. Those losses are, for the most part, permanent. Spectrum does not get degraded, but there is a congestion problem that can result from too many people broadcasting, low quality receivers, etc.

Spectrum management means different things. It is the process by which alternative uses of spectrum is managed. It can also be thought of as how to accommodate the demands of users and uses of spectrum. While there may not be a single definition of spectrum management, what is clear is that spectrum management requires thinking of rules. They may be formal (enforced by government) or informal (norms, nonbinding agreements, and reciprocity arrangements without external enforcement).

Most significantly, spectrum management is an institutional arrangement. This requires consideration of physical constraints and technology. The institutional aspects require thinking about history, law, path dependence, and politics. Technology has a human element as well, as spectrum is a socio-technical system.

a. Exclusive Licensing

The ability to transmit and receive on specific frequency bands is essential to any wireless communications, such as Wi-Fi, cellular networks, broadcast television and radio and more. Countless other technologies rely on radio transmission and so require access to spectrum, such as radar, satellites, telescopes, IoT devices etc.

Spectrum sharing is the original form of spectrum use. In the early days of radio, electromagnetic spectrum was a shared resource: anyone could broadcast if they had the equipment and know how. Even through there were few rules and the almost none were enforced, it was a free for all (Douglas 1987). The early broadcasters figured out ways to manage their access to spectrum.

They had to share the band since their signals competed with those of other broadcasters on the only frequency allocated for commercial use.

As more people began broadcasting, and it became clear just how valuable radio was, there was pressure to change institutions. Broadcasters formed an association, the National Association of Broadcasters, in 1925 to aid in their goal of getting Congress to establish a more effective system to manage spectrum. And Congress responded fairly quickly, with the Radio Act in 1927, which established Federal Radio commission, followed by the Federal Communications Commission in 1934. These acts declared that Congress has the authority to manage spectrum in the public's interest, including to promote commercial broadcast and public and community uses of spectrum.

In the case of electromagnetic spectrum, the problem with open access—the absence of exclusive property rights—is that there are too many users, conflicting uses, inconsistent technical parameters (e.g., transmission power), or combinations of these factors. Interference results, and the usefulness (hence the value) of spectrum declines. However, property-rights regimes require definition and enforcement of allocation rules. Some possibilities for allocation rules include beauty contests (political allocation), market allocation, and lotteries. Coase (1959), noted that spectrum has value and thus should be assigned to their most valuable user (and use). Despite Coase's insights, Congress decided that bureaucratic hearings were the best way to assign spectrum. Hazlett's (2017) economic history of spectrum explains the evolution of spectrum policy in the US from bureaucratic beauty contests to modern spectrum auctions. It took nearly four decades before auctions were used to allocate spectrum (Hazlett et al. 2011). Thus, it is necessary to consider spectrum, and change in the property rights to spectrum, as a political issue.

b. Liberalized Licensing and Spectrum-Sharing Arrangements

Examples such as television white spaces illustrate how spectrum may be underused or misallocated within an overall regime of exclusive access. The exponential growth of demand for wireless broadband necessitates spectrum reforms such as spectrum sharing (in frequency, time, or geographic dimensions, or any combination thereof). Deployment of fifth-generation (5G) mobile-communications technology will further increase demand for spectrum access. LSA and Spectrum Access System (SAS) facilitate the more intensive use of spectrum necessary to accommodate the exponential growth of mobile-phone service. In these sharing arrangements, underutilized spectrum is shared, on a licensed basis, between incumbents and mobile operators, subject to agreement on frequency, location, and time-sharing conditions. LSA enables mobile operators to access additional spectrum below 6GHz and gives them the regulatory certainty they need in order to invest in 5G, while other spectrum-sharing regimes do not guarantee mobile operators protection from harmful interference. SAS enables more users to coexist on the spectrum band thanks to spectrum-sensing techniques (Massaro 2017).

The FCC's Spectrum Task Force Report of 2002 considered spectrum sharing a mere possibility. With the President's Council of Advisors on Science and Technology (PCAST) Spectrum Report of 2012, mere possibility shifted to the concrete policy of "multilane superhighways, where the lanes are continuously shared by many cars, trucks, and other vehicles." The Obama administration's presidential memorandum of June 2013 called on the National Telecommunications and Information Administration (NTIA) and FCC to promote spectrum sharing, with a goal of freeing up 500 MHz of spectrum for licensed and unlicensed wireless broadband by 2020. To achieve the goal, operators require viable and scalable options in real-world settings spanning the spectrum of frequency bands, applications, and end users.

Commercial wireless is typically based on exclusive use. For example, in "overlay" sharing arrangements, an entrant or secondary user is granted usage rights subject to the primary users' requirements or usage. Overlays emerged with cognitive radios and cognitive networks and was extended to sharing methods based on databases—such as TV white spaces, CBRS, and Licensed Shared Access (LSA). Functional requirements of overlays include accessible databases to facilitate the sharing and trading of spectrum access.

Weiss and Lehr (2009) propose a typology of sharing arrangements based on the definition of rights (primary versus secondary) and the enforcement of rights (cooperative versus noncooperative). With primary sharing arrangements (for example, unlicensed bands), all users have equivalent (or equal) rights to access the spectrum. Under secondary sharing arrangements (such as TV white spaces, CBRS, and LSAs), users have a hierarchy of rights in which primary users (incumbent license holders) have superior rights to secondary users (spectrum entrants). In cooperative arrangements, an ex ante agreement is struck between the sharing parties. Secondary markets characterized by voluntary exchange are an example of cooperative sharing (the parties agree on use), as do sharing techniques such as LSA. With noncooperative sharing, users do not coordinate their use ex ante, relying instead on technology to govern "traffic."

3. Applying the Theory of Polycentricity to Spectrum-Sharing Practices

The excludability approach tends to see spectrum management as a mechanism design problem. This perspective has given rise to sophisticated analysis of alternative auction mechanisms in the context of spectrum management. Consequently, the FCC also spends significant resources on attempting to define and manage interference as well as on enforcement of policies and property arrangements. The political problem is a classic one in public choice and the exclusive property-rights school can help explain why efficient institutions are not always chosen. But it also presumes that the private property rights are the most significant (often only) institutional arrangement. Here, we argue that it makes sense to think of the institutional arrangements governing spectrum as a continuum from excludability (Coasean) to self-governance (Ostromian).

Spectrum regulators issue numerous kinds of licenses. In some cases, licenses grant *operating licenses*, that is the rights to transmit in certain bands (as, for example, in amateur radio licenses or LEO satellite licenses) and in others they grant excludable rights to particular time/space/frequency regions, *spectrum licenses*. The former are the kind that we consider in this section. If spectrum licenses are *liberal*, license holders have considerable freedom to use this as they see fit. Consequently, licensed spectrum may involve a commons, private or public. We observe that excludability is always imperfect, so that what is left is often shared.

It is well understood that both commons and private property are property regimes. Our point is that the commons approach is more explanatory for this resource than it may seem. It is not prospective to argue for sharing; sharing has been a major foundation for spectrum governance, and it is likely to become more prevalent in the future. For example, the Internet of Things (IoT) is built around unassigned spectrum and will consist of billions of devices, mostly without excludable rights. But this requires governance, which suggests that an Ostromian perspective will increasingly be useful. Another example is amateur radio. If we hope to preserve this community, and its self-governing features, the rationale will be in part on being able to understand its open-source innovation model. We can also consider the sharing that must occur with the Low Earth Orbit (LEO) mega-constellations (such as Starlink, OneWeb, Kuiper, and Amazon's fleet to support its broadband network) The common thread among these examples is that there it is not efficient to develop a property system in these cases. Here, the FCC makes an allocation and the users of that allocation coordinate on its use.

Sharing goes further than this: indigenous people around the world are demanding access to spectrum, on their terms. Sharing spectrum can be the intermediate step in the path to their spectrum sovereignty. And with more sovereign control, they may choose to rely more on unassigned bands, for community use. Sharing of spectrum by radio pirates (where sharing is not legal, but where a sharing approach offers insight), has existed since the creation of the FCC and the early prohibitions on pirate broadcasting. Since then, rules for community use and LPRM have been movement toward sharing of spectrum.

The first step in determining spectrum property rights requires defining how large a slice a prospective use gets. That is always going to be challenging because the government might err on the side of too much spectrum, which means it will be underutilized. A second issue is lobbying. Once the government establishes property rights to spectrum, changing the initial allocation will be challenging because the owners become an interest group with an incentive to maintain the status quo, often because of sunk costs made by incumbents to use that spectrum. The second step is determining the "parcels" of spectrum and then assigning these parcels to particular users. This is especially problematic for something as valuable as spectrum. A third issue is that, according to Posner and Weyl (2017), all property arrangements create monopolies. Monopolies can be a source of inefficiency, as they prevent innovation and resources from being allocated to their most highly valued uses.

More fundamentally, the property rights arrangements above are all centralized in that the government is the source of property rights. Yet we know from the law and economics of anarchy that order often arises without law (Ellickson 1991). People routinely come up with their own rules to govern their behavior, and those rules often work well (Powell and Stringham 2009). In many instances, these rules are efficient in that the absence of a role for government is better for society than government enforcement (Leeson 2006). Furthermore, the economics of anarchy has proponents in the spectrum realm. Benkler (2002) argues for abolishing centralized rules governing the spectrum. The reason is that there are substantial gains from sharing the electromagnetic spectrum, and sharing defines the internet age (Benkler 2004). More importantly, sharing enables wealth creation in the networked economy (Benkler 2006, 2013).

Benkler (2002) recasts the policy problem as a choice between two models. One is property rights to spectrum, which the government applied to radio. The second model deploys wireless equipment without licenses or property rights. The latter is the spectrum-commons model. With a spectrum-commons model, the market is in intelligent end-user equipment rather than infrastructure rights. The advantage of open wireless networks is greater capacity, more growth, more innovation, and, ultimately, more consumer welfare.

What makes open wireless a feasible alternative to licensing is technology, specifically the ability to divide up the spectrum using new and better machines. In fact, with such technology, the entire property rights argument might unravel. Werbach (2004) argues that the entire metaphor of the commons is inappropriate for spectrum. Spectrum is not a physical resource like an oil reservoir, forest, or fishery, where the property rights approach has been so fruitfully applied (see, for example, Libecap 1989). The reason is that what constitutes the spectrum depends on technology. It is always changing, and so the property rights approach and the arrangements for governing it are necessarily inappropriate. Thus, both sides of the debate between exclusive property rights and unlicensed sharing (the spectrum commons) are wrong because they fail to grasp that there is no such thing as "spectrum." Since spectrum is an intellectual construct whose utility rapidly breaks down as technology develops, any policies to allocate it represent artificial constraints that fail to exploit the full capacity of what Werbach (2004) calls the supercommons and produce inefficient outcomes.

The supercommons model does not call for complete anarchy. Rather, it suggests replacing the legal regime of licenses with an unlicensed regime in which law still has a place. For example, tort law could be used to deal with interference. But Werbach (2004) does go a step further in suggesting universal communication privilege: allowing anyone to transmit anywhere, and in any way, as the baseline for wireless communications, with liability backstops and safe-harbor mechanisms serving to prevent interference and to resolve boundary disputes. The default rule of unfettered wireless communications comes close to spectrum anarchy, and, like Benkler, Werbach suggests substantial gains: unlicensed communications promise to provide an even more significant platform for innovation, user empowerment, and value creation. This would also be a poor regime for passive users, as they require broad areas with limits on transmission .

The property rights and anarchy approaches are sometimes viewed as competing, but they are in fact complementary. The property rights approach is an unambiguous improvement over beauty contests, though unless secondary markets work well and there is some constraint on rent-seeking, there will likely be too much property owned by license holders at the expense of innovators. But a continual push for unlicensed spectrum also has merit, as that is likely to result in innovation as well. In other words, the end point of reform is to push for radical markets, and when they are robust enough, the role of government in allocation can shrink to nothing. As technology develops, it might not even make sense to have property rights. Indeed, what we find empirically is that c

4. Cases of Informal Coordination in Spectrum Sharing

In this section, we provide several cases of informal coordination in three contemporary spectrum-sharing arrangements

a. Television

Broadcast television blossomed in since the 1940s, but the television band was described by FCC Newton Minow as a "vast wasteland" (Werbach 2011) and by Hazlett (2008) as the "motherlode of underutilized spectrum." The problem is that in 1941, the FCC allocated each television broadcaster a 6 MHz band, but not the television band encompasses over 400 MHz allocated to

60 channels, with 6 MHz each, and over 1,700 full-powered television stations (Hazlett 2008). The problem is that there are lots of vacant channels to serve as buffers despite many other uses, including more broadband access, but the FCC rules only allowed high-powered video transmissions, despite possibilities for overlay rights, or simply giving away all the white space or selling it.

From an economic perspective, it is an anticommons: too many users have property, resulting in too little use of a valuable resource. Possibilities include making it an unlicensed space (white spaces become unlicensed spaces), enabling wireless broadband connection.

In 2008, the FCC issues an order that allowed users whose equipment fits certain technical requirements (including geolocation capability and ability to access FCC databases) use white space without a license, with the requirement that a database be established with information on locations and channels that can be used with unlicensed devices.[1] As of February 11, 2021, the FCC revised its rules in order to increase the ability of unlicensed white-space devices to deliver wireless broadband services in rural areas and to promote innovation in narrow-band Internet of Things devices in TV white spaces.[2]

b. Wireless

The promise of sharing is illustrated with Dewayne Hendricks work on WiFi for everyone – he criticized experts who say congestion and interference in unlicensed spectrum prevent WiFi networks from scaling up successful. Examples – Wireless Broadband Access Network Coordination organization, which brought together 50 WISPs to prevent congestion and interference; free Wi-Fi networks at the county level; and many others. His vision was a Wi-Fi cloud over the entire state.[3]

A spectrum "commons" will spur new technology and more efficient use of the airwaves. Over time, it would encompass much of the radio spectrum. The key is to use technologies that exist or can be fast tracked – no more digital divide or last-mile problem. The problems are FCC, Congress, etc. The reason – too much consideration of interference, and too much spectrum reserved for groups for exclusive use, leaving too little spectrum to support wireless broadband. Government restricts technologies like spread spectrum, ultrawideband, and cognitive radios that would enable everyone to share frequencies (spectrum overlay). The Turtle Mountain Chippewa Reservation in North Dakota provided an opportunity for the tribe to experiment – Hendricks would set up a wireless network, meeting FCC requirements governing frequency, power, and transmission, but they would then push the envelope to develop the best technology.

At Turtle Mountain Chippewa Reservation in North Dakota, he's installing a wireless network. In its initial form, the system will meet FCC requirements governing frequency, power, and transmission technology. But not for long. Hendricks' mission is to build the best system possible

[1] "Unlicensed Operation in the TV Broadcast Bands; Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band," ET Docket Nos. 04–186 and 02–380, Second Report and Order and Memorandum Opinion and Order, 23 FCC Rcd 16807 (2008) (White Spaces Second Order). As pointed out by Jackson et.al. [cite] the market adoption of white space devices was poor because of technical limitations of the order.

[2] https://www.federalregister.gov/documents/2021/01/12/2020–26706/unlicensed-white-space-device-operations-in-the-television-bands.

[3] https://www.wi-fiplanet.com/wireless-plan-to-bring-1-gbps-to-homes/

- even if it's illegal - and he intends to use every tool at his disposal. Should the FCC crack down, the tribal leaders will hoist the flag of Native American sovereignty, asserting that they can do whatever they want with the sky above their reservation.

c. Amateur Radio

In our view, AR is an unassigned spectrum model because AR is valuable for wireless future, it needs to be managed as unassigned spectrum, and is an interesting example of unassigned spectrum because of its polycentric governance features. To consider the value of AR, we consider it as a source of open-ended innovation that builds wireless capacity in technology. It does so by providing opportunities to cultivate skills and provides for experimentation. As far as the governance aspects, we explain how limiting commercial use is appropriate and why the commercial aspects do not apply. As far as the governance, AR emerges as an example of how polycentric governance can work, as the FCC currently provides for opportunities for self-governance to a limited degree

Amateur radio is sharing of spectrum. Commercial use wants the spectrum. The regime establishes a place for amateur radio. And it does not assign it. To manage the commons, it is very much an Ostromian process. It is Ostromian in that there is a constitutional rule (Part 97, which specifies FCC rules for amateur), but also has collective choice rules (amateur radio clubs). There are also norms for governing use of radio.

This enables sharing of the resources. It is not excludable rights by any means. Amateur has an allocation, and the specific broadcasts are unassigned. There is no "property right" to broadcast to space satellites.

Thus, by itself, the above suggests that amateur radio has provided value to its users and to society at large, but it does not refute the perspective that those benefits might have been realized in any case, and potentially at lower total costs, had the amateur radio resources been allocated to commercial or other public uses (e.g., allocated to mobile broadband, television broadcasters, or emergency services – whether to investor-funded, private licensees or government-subsidized providers of public services)

5. Conclusion

Spectrum has always been shared: radio broadcasters shared it, and when Congress declared public interest, it was imposing sharing. Some for private, some for public use, some for amateur. It was never a pure "excludable" regime. So it makes sense to think of it as a continuum of sharing.

Beyond that, it makes sense to think of Coase and Ostrom as the two endpoints of a continuum. Neither has priority. The only lesson of the property rights approach is that the regime must reflect transaction costs. That means it makes no sense to prioritize one over the other. That is for the technology and human factors and our societies to decide.

Spectrum has not yet been informed by Ostrom's approach as much as it could. This is an oversight, as technology and the physical space is making it more likely that sharing is going to be the way people allocate resources. The unlicensed and unassigned spectrum is an Ostromian approach to spectrum, even if it was not informed specifically by Ostrom. By more closely aligning thinking about spectrum with Ostrom's ideas, it may be possible to improve the design of spectrum policy.

This might be especially important in developing spectrum policy for the Internet of Things, for spectrum "rights" in outer space ("rights" because it is not clear who has rights, except for access), and for landscape-level rights for passive uses of spectrum. Rather than see these as an anomaly from the excludability approach, it is useful to see technology and the environment (the physical world) as determining where the rights system ends up.

There are other aspects of sharing, such as expansion of mobile systems and sharing of infrastructure. Providers needed more towers but sharing was necessary. Eventually, telecom providers sold towers to specialized companies, such as CrownCastle and American Tower, who then provide the shared infrastructure. It is private property, but the telecom companies share it. It is considered a way to reduce costs, one that involves sharing.[4]

Radical markets seek to create semi-public property rights, such as usufruct rights in Guatemala and El Salvador, as well as Sweden considering requirements that new licensees share spectrum. Common law could provide a framework to address disputes over rights. Other possibilities include reallocating property rights, such as with white spaces, so that it can be sold. The rationale for such reallocation could be encourage greater innovation, as well as in recognition that the original allocation may not have been equitable.

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[4] See, for example, the GSMA report on infrastructure sharing: https://www.gsma.com/publicpolicy/wp-content/uploads/2012/09/Mobile-Infrastructure-sharing.pdf .

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