# Institutional Diversity in Spectrum Sharing: Exclusive and Nonexclusive Property-Rights Regimes

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**Abstract** In the past several decades, spectrum policy in the United States has shifted from a case-by-case "command-and-control" framework to a "Coasian" framework, in which exclusive but flexible spectrum rights are assigned via market mechanisms. In this paper, we argue that the observation of both formal and informal spectrum-management practices necessitates a policy framework that allows comparative study across a wider array of governance structures, ranging from exclusive access to spectrum commons. We propose an alternative policy framework, informed by Elinor Ostrom's research on polycentric systems, and use this lens to assess the viability of alternative spectrum-sharing solutions, particularly unlicensed spectrum. Our analysis suggests that "unassigned" spectrum bands -- i.e. communal ownership or private commons -- implemented within a flexible-licensing regime can mediate between the costs and benefits of exclusive and nonexclusive access.

**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

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.

The modern concept 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 that have been historically observed in spectrum allocation highlights that the question of *how* spectrum should be shared across competing uses lacks a clear answer.

In this paper, we argue that the theory of polycentricity, pioneered by Elinor Ostrom, provides a useful lens through which future spectrum-management decisions can be considered. Particularly we present an alternative spectrum-policy framework focusing on acknowledging the potential value of both formal and informal governance institutions. In the context of spectrum allocation, formal governance rules require a regulatory body, e.g. the Federal Communications

Commission (FCC), to enforce pre-agreed-upon contractual terms. In contrast, informal spectrum sharing involves spectrum users independently coordinating on self-enforcing sharing agreements, similar to the formation of social norms.

United States spectrum policy in recent years has demonstrated a shift from a command-and-control regulatory framework, whereby spectrum allocations are assigned on a case-by-case basis by the FCC, to what we designate as a "Coasian" framework, where flexible-use licenses granting licensees rights to exclude others from allocated spectrum parcels are allocated via market mechanisms. However, "unlicensed spectrum" remains a popular buzz word in the spectrum community, and the success of the Wi-Fi industry -- which largely operates using bands where users have limited formal rights to exclude others – suggests consideration of a broader policy framework which acknowledges the possibility of informal spectrum sharing in non-exclusive regimes.

We appeal to insights from the literature on relational contracting within and between firms to describe channels through which assignment of exclusive property rights can undermine more productive forms of complex informal coordination. There are thus costs and benefits to both exclusive and non-exclusive property rights regimes in spectrum management. We argue that unassigned spectrum bands (i.e. private spectrum commons) implemented within a flexible-licensing regime can mediate between these costs and benefits.

The paper is structured as follows: Section 2 provides a brief overview of spectrum management, focusing on the evolution of governance practices for spectrum allocation in the United States. Section 3 discusses the concepts of formal and informal governance in the context of the game-theoretic literature on relational contracting. Section 4 describes the proposed policy framework and Section 5 discusses the tradeoffs present in choosing between exclusive and non-exclusive spectrum-governance regimes and proposes the concept of "unassigned" spectrum as a potential way to moderate between the costs and benefits of the two types of regimes. Section 6 concludes.

## 2. Institutional Aspects of Spectrum Management

When first discovered, the electromagnetic spectrum was a shared resource: anyone could broadcast if they had the equipment and know how. There were few rules and the almost none were enforced (Douglas 1987) – the setting was reminiscent of a resource commons (cite Ostrom). Early broadcasters had to design their own governance structures to manage their access to spectrum. Spectrum sharing was a necessity since signals competed with each other when transmitted on popular frequency bands. As more people began broadcasting, and it became clear just how valuable radio was, there was pressure to change institutions. Broadcasters formed associations, first the Radio Broadcasting Society in 1922[1] and subsequently the National Association of Broadcasters, in 1925 to aid in their goal of getting Congress to establish a more effective system to manage spectrum.

[1] "The March of Radio" p 457, https://worldradiohistory.com/Archive-Radio-Broadcast/Radio-Broadcast-1922-10.pdf

The Radio Act in 1927 established the 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 uses of spectrum. These developments were consistent with Demsetz's (1967) theory of property rights and Olson's (1965) logic of collective action. The increase in value of property rights to spectrum, and the threat to commercial broadcast posed by interference, gave broadcasters an economic incentive to establish formal rights governing spectrum access. The Supreme Court maintained that there was a cacophony of competing voices before regulation (NBC v. United States) and that private sector allocation would result in "chaos" (Red Lion v. FCC). Thus, broadcasters were issued rights to access spectrum via "beauty contests," or case-by-case determination by the FCC. The FCC not only enforced rules regarding spectrum use, but also took responsibility for designing them.

Ronald Coase noted in a series of papers that spectrum has value and should be assigned to its most valuable user and use via market mechanisms (Coase, 1959, 1960). In his 2017 book, former FCC chief economist, Thomas Hazlett, describes how Coase's proposal for spectrum assignment was largely ignored for decades -- formal auctions for flexible-use spectrum licenses were not implemented until the mid-90s. Hazlett and other spectrum-policy experts argue that this delay held up the development of numerous valuable spectrum-based technologies, particularly mobile-communication services (Hazlett, 2017).

In recent years, US spectrum regulation has demonstrated a shift away from the original command-and-control paradigm, with significant regulatory efforts placed in designing formal market mechanisms to allocate flexible-use licenses. Flexible-use licenses, or "liberalized" licenses, gives licensees the right to exclude others from using their specified band, but limit centralized restrictions on services, technologies, and business models associated with the band. This flexibility gives incumbent license holders strong incentives to generate their own contracts with third parties and maximize the aggregate social value of their allotted spectrum band. In a flexible-licensing regime, the task of designing spectrum-sharing arrangements is effectively reallocated from central regulator (i.e. the FCC) to spectrum stake holders (e.g. wireless carriers, TV broadcasters, technology and app developers, etc.). The role of central regulation can consequently be reduced from case-by-case spectrum assignment to simply enforcing licensee exclusion rights and the terms of formal contracts struck by spectrum shareholders themselves.

The benefits following the shift to this more "Coasian" policy regime were widely felt, particularly as evidenced by the explosion of wireless technologies beginning in the late 1990s. The smart phone industry is a prime example, where flexible licensing has accommodated a complex structure of contractual relationships between wireless carriers and third-party hardware and software developers (Hazlett, et. al. 2023).

Nevertheless, a continued push for "unlicensed spectrum" remains (Hazlett, 2017, ch. 16). Unlicensed spectrum bands are reminiscent of the initial periods of spectrum usage in which any operator with the appropriate technology and know-how could transmit. Several modern unlicensed bands do exist in the current US spectrum allocation. Particularly notable are frequency bands used to sustain Wi-Fi networks. Fast technological development and growth

observed in the Wi-Fi industry suggests potential value in considering non-exclusive rights regimes, such as unlicensed spectrum. Optimal usage of non-exclusive regimes in spectrum management is an important question facing regulators.

One perspective is that the spectrum community is currently at crossroads. Stakeholders recognize the value of resource sharing but are faced with two seemingly different "styles" of organizational management: Exclusive regimes can protect economic interests and incentivize the development of complex formal rules to guide the flow of spectrum in an orderly manner. Non-exclusive regimes lower barriers to entry for new spectrum uses, potentially promoting more open-ended forms of innovation, but require stakeholders to generate their own self-sustaining governance rules. To some degree, this tension relates to a classic problem facing leaders of many organizations: How can we establish ordered production without inhibiting the freedom to adapt?

An attempt to accommodate heterogeneous regimes in a single band is a recent interest of spectrum regulators. For example the Citizen's Broadband Radio Service (CBRS), originally allocated to the Dept of Defense in the U.S., was subsequently sub-divided into three tiers with different usage priorities. The highest priority is associated with the "Incumbent" tier (the Dept of Defense in this case). If the incumbent wishes to use the band, all other tiers must immediately vacate. The second priority tier is referred to as PAL (Priority Access License), in which users might purchase a license at auction for a particular band. The PAL gives these users priority over the General Authorized Access (or GAA) users. GAA operates much like an unlicensed band, though formally speaking, it is not unlicensed. The priorities are managed by a computer-based Spectrum Access System (SAS) that determines who may use which frequencies at a particular time and location.

Another closely-related policy issue is the question of international spectrum governance. International coordination is desirable as radio waves often do not respect national borders and equipment and transmitting laws may differ across jurisdictions. However, international disputes regarding spectrum can be difficult to resolve as international regulatory institutions must be jointly ratified by separate sovereign nations with potentially conflicting interests. International coordination of spectrum management is currently handled by the International Telecommunications Union (ITU), which is a specialized agency of the United Nations. Due given fast-growing commercial and non-commercial interests in implementing satellite technologies, recent regulatory attention has turned to considering potential reform in the ITU's assignment process for outer-space spectrum-usage rights (SURs).

We see the spectrum community not as facing a crossroads, but rather a vast set of traversable paths -- or governance structures -- that achieve balance between order and adaptation in different ways. While governance of the CBRS band is an example of how multiple governance goals can be achieved in a single band, many other arrangements are conceivable. We do not argue for a one-size-fits all solution for every instance of spectrum sharing, nor do we believe one exists. However, we do feel that interdisciplinary sources can be aggregated to provide the conceptual framework and mathematical tools necessary to rigorously approach this question. We develop this argument in the remainder of the paper.

## 3. Formal vs. Informal Resource Sharing

Economists often distinguish between formal and informal governance practices. Formal governance involves the use of a powerful third-party institution to enforce operational rules which have been pre-agreed upon. The well-known Coase theorem specifies that, if exclusive property rights are established over a resource and transaction costs are null, self-interested parties should be able to bargain to an efficient set of formal resource-allocation rules on their own. The technical field of mechanism design has developed a general mathematical framework for studying the design of formal governance rules.

Formal contracting can be a costly task, however. A truly complete rule set must specify a reaction for every possible event contingency, regardless of how unlikely. Furthermore, even if such a contract could theoretically be underwritten, regulatory bodies must be able to credibly implement the contracts' terms. Not only does credible implementation require that the regulatory body have the capacity to punish contract violators, it also necessitates establishing monitoring infrastructure to assist the regulatory body in verifying contract contingencies that have occurred. All of this can be expensive, sometimes prohibitively so.

Informal governance, in contrast, does not rely on a third party to monitor and enforce contract terms (Alessi, 2003). Agreements of this form are sustained by implicit understandings of action and consequence by economic actors. An employee who works hard can expect to get promotions and raises, while an employer who rewards employees for good performance can expect to get high quality work. If the alternative to this arrangement -- e.g. low compensation and low effort – is undesirable to both parties, a productive relationship can be struck based on a joint understanding of cooperation and its positive and negative consequences.

Informal agreements extend far beyond transactions within firms and are crucial for sustaining a variety of social institutions, including the formation of constitutions, nation-states, and centralized governments themselves (North and Weingast, 1989). Informal agreements also play an important role in sustaining cooperation in complex environments where third-party monitoring may be prohibitively costly. In such environments, interacting parties may be able to generate their own forms of coordination based on signals observed only by those in the particular action arena (Hayek, 1945).

The game-theoretic literature in relational contracting demonstrates, via mathematical models, how strategic and self-interested parties can coordinate on Pareto superior equilibria in settings where interactions are repeated (e.g. Levin, 2003). In some cases, these relational contracts can unlock more social value than the use of available formal instruments (Baker et. al. 1994), and in others, poorly assigned formal property rights can undermine more productive relational agreements by altering the reneging temptations of cooperating parties (Baker et. al., 2002, 2011).

Considering the economics of formal vs. informal governance provides insight into tensions inherent in exclusive and non-exclusive property-rights regimes. Designating exclusive rights to a resource can give economic actors high-powered incentives to develop sophisticated formal resource-sharing rules on their own and invest in the infrastructure necessary to legally enforce

them. Exclusive rights, however, can degrade incentives to cooperate in potentially more sophisticated informal agreements. Consequently, for a particular set of economic actors and a given resource, the relative value of an exclusive regime as opposed to a non-exclusive regime depends would presumably depend on the preferences of the regulatory agency tasked with enforcing resource-sharing rules as well as its capacity to monitor the relevant economic activity.

## 4. Polycentricity as an Alternative Spectrum-Policy Framework

Nobel-Prize winning political scientist and economist, Elinor Ostrom, describes a *framework* as a tool for "[identifying] the elements (and the relationships among these elements) that one needs to consider for institutional analysis". Frameworks provide "a metatheoretical language that is necessary to talk about theories and that can be used to compare theories" (Ostrom, 2006). Developing a comprehensive policy framework for spectrum management is important as it gives policy makers a concrete tool to compare governance structures and make specific predictions regarding the viability of various spectrum -strategies, in relation to available alternatives.

Asserted complexity in determining the socially optimal use of spectrum was initially used to justify a "command-and-control" policy framework whereby exclusive rights to spectrum were held solely by the central regulator who solicited information from spectrum stakeholders to design formal governance rules guiding the allocation of spectrum across societal uses. The shift to a Coasian policy framework – i.e. establishing formal markets for flexible spectrum licenses -- simultaneously mitigated the incentives for interest groups to lobby for spectrum allocation and removed the burden of designing formal governance rules from the hands of central regulators.

Nevertheless, the potential value of non-exclusive spectrum regimes is evidenced by success in industries such as Wi-Fi and additionally has intuitive economic benefits in the theory of relational contracting. Exclusive rights are a core requirement of a Coasian regime but are sometimes at ends with self-governance. Thus, comprehensively comparing competing spectrum-policy proposals may require a broader policy framework that facilitates consideration of coordination on both formal and informal institutions.

We argue that the theory of polycentricity, and its corresponding analytical framework, the Institutional Analysis and Development (IAD) framework, can provide spectrum policy makers with a robust tool for comparative analysis across a much wider array of spectrum-governance options. The theory of polycentricity was pioneered by Elinor Ostrom and views a community as composed of autonomous strategic agents who base decision making around both formal laws imposed by regulators as well as informal social norms and implicit understandings. The IAD framework centers around an "action arena" where participants interact with each other based on formal and informal "rules" developed in higher spheres of interaction, which themselves can be modeled as separate, but interacting, action arenas.

The choice between an exclusive property-rights paradigm versus common-pool resource management is often viewed as discrete. Policy makers can either designate exclusive property rights or refrain from doing so. The IAD framework, however, does not require a choice. Ostrom's insight was to develop a general framework for common-pool resource management,

with technology and human factors determining which regime is best. Hence, it generalizes the earlier work in the neoclassical tradition by allowing consideration of a broader array of governance structures ranging from exclusive property rights to pure resource commons.

In the context of spectrum allocation, virtual parceling of the electromagnetic spectrum is often recommended as a method for implementing allocation outcomes that would be possible in a regime with consistent and complete spot markets for exclusive spectrum access rights. Virtual parceling involves identifying a set of observable dimensions over which spectrum rights can be defined e.g. time, location, transmission power, etc. Emerging distributed ledger technologies, such as Blockchain, and smart contracts over the virtual partitioning can then facilitate spectrum sharing between users of a given frequency band (Weiss et.al. 2019, Bustamante et.al. 2022). Indeed, a fine enough virtual partitioning combined with a rich enough set of marketed smart contracts could theoretically facilitate Pareto optimal allocations, in the style of the classic general-equilibrium model of Arrow-Debreu securities (Arrow and Debreu, 1954). However, given the fast-evolving and frequently growing nature of socially valuable spectrum uses, constructing a virtual partitioning that would be fine enough to support full allocative efficiency is likely impossible. Furthermore, implementation of smart contracting using distributed-ledger technologies is still in its infancy and miscoordination arising from poorly constructed or incomplete smart contracts remains a risk.

"Spectrum anarchy" lies at the other extreme where no formal authority exists to delineate or enforce property rights over spectrum and any user can transmit as they see fit. Such a regime does not directly imply the tragedy of the commons however, as informal coordination such as handshake agreements and perhaps more sophisticated relational contracting may develop. However, such agreements have historically had the most success in small homogenous communities. Given the vast scale of spectrum use today, as well as modern society's reliance on key spectrum applications such as internet, mobile phones, and emergency services, pure spectrum anarchy over the entire electromagnetic spectrum would likely be a risky and uncomfortable arrangement in contemporary times.

The various "hybrid" forms of governance that have been recommended to facilitate efficient spectrum sharing can be perceived as lying in between the above two extremes. Unlicensed bands do not exclude operators from using particular frequencies but do typically place some formal restrictions on their practices such as power-level and equipment requirements. Overlay arrangements, feasible in flexible-licensing regimes, grant primary access rights to a specified spectrum user, but effectively allow that user authority to withhold exclusion from their assigned band for approved secondary users, at their discretion. The three-tier structure of governance in the CBRS band is yet another hybrid form of governance, combining elements of both unlicensed and flexible-licensing regimes. The Ostromian approach allows us to study these different governance structures in the context of each other by considering how they differ in terms of their reliance on formal access rights versus informal coordination.

## 5. Flexible Licensing vs. Unlicensed Spectrum: The Case for "Unassigned" Spectrum

The historical progression of spectrum policy in the United States highlights that designing and implementing flexible governance rules is a complex and costly task. Formal regulatory bodies, such as the FCC, are often tied down by a variety of frictions which result in inefficiently unresponsive resource-sharing arrangements. These frictions include lobbying and information manipulation from self-interested parties, difficulties in predicting where the march of science will eventually lead, and limited bureaucratic incentives to exert effort in consistently updating spectrum policy. It is consequently not a trivial question to determine who should own decision rights over designing and implementing spectrum-sharing rules. Flexible licensing is an intuitive response to the tension described above. By allowing spectrum-stake holders to strike up their own contracts with each other, the task of designing and implementing spectrum-sharing rules can effectively be delegated to self-interested parties who can better internalize the costs of these tasks. Nevertheless, formal contracts still require a regulatory body to monitor and enforce their terms, and the resulting residual contract incompleteness can lead to underutilization or misallocation of spectrum.

Unlicensed spectrum is often suggested as an alternative to spectrum licensing, as it can give spectrum access to a broader array of users and limit barriers to entry into the spectrum industry. Coordination in unlicensed spectrum bands is largely informal in nature as formal regulatory bodies do not enforce private spectrum-sharing agreements struck by spectrum users. In a true spectrum commons, no one party has the ability to exclude another from using the resource in any particular way. Considering recent organizational literature in relation contracting, this can be a positive thing as it can diminish strategic incentives for self-interested parties to renege on informal cooperative agreements. However, open-access regimes that cannot restrict resource usage to a particular class of users are prone to the classic *tragedy of the commons* (TofC) problem, in which scarce resources are overused or misallocated (Eggertson, 2003). As spectrum demands grew in the 2015 timeframe, wireless carriers began exploring how commercial services (4G LTE in particular) could be supported over unlicensed bands. This led to loss of quality for "traditional" unlicensed users, WiFi in particular (Sathya et al. 2021).

Furthermore, political and bureaucratic issues further complicate effective implementation of unlicensed spectrum. Most currently implemented unlicensed spectrum bands cannot be characterized as pure spectrum commons. The FCC places various restrictions on usage of the band including power level and technology requirements. These restrictions strike a particular balance in the tradeoffs connected with the allocated spectrum, which limit some possible uses of the spectrum. Second, once allocated, unlicensed spectrum bands may be difficult to reabsorb if more productive uses for the band arise in the future. The multiple-decade delay in reallocating TV-broadcasting bands to cellular services serves as a compelling example of how vested interests can impede reallocation of resources to more socially productive uses (Hazlett, 2017), and similar tensions are currently arising in discussions of repurposing the CBRS band.

In a series of recent papers, we introduce the concept of "unassigned" spectrum. In an unassigned spectrum band, spectrum is allocated to a group of individuals (usually for an intended purpose) but specific usage rights are not formally assigned to individuals within that group. Rather, the band is treated as a *private commons* whereby a regulatory body acts as a

gatekeeper tasked with maintaining the integrity of the band's userbase while allowing members of the club flexibility to strike up their own usage rules (perhaps adhering to some general guidelines). An interesting case of unassigned spectrum lies in spectrum bands allocated for non-commercial, amateur-radio (AR) activities. In a separate paper we discuss how AR activities are governed via constitutional rules which are largely enforced informally. We argue that this structure well accommodates amateur-radio services, which are open-ended in nature and difficult to describe via formal contract.

A polycentric framework which treats regulators and spectrum stakeholders as autonomous strategic agents allows us to consider governance structures in which unassigned spectrum bands are implemented by incumbent owners of flexible spectrum licenses. One advantage of this approach is that private spectrum commons can be established by self-interested parties who potentially have better information regarding the types of open-ended services that would be valuable to them. This gives discretion over determining the size and userbase of unassigned bands to parties who have direct financial incentives to internalize the costs of managing spectrum usage in those bands.

Alternatively, government agencies can establish and subsidize non-profit organizations to bid for flexible licenses and establish unassigned bands at their discretion. For example, in the case of amateur radio, the Amateur Radio Relay League (ARRL) serves as a centralized volunteer organization tasked with establishing guidelines for appropriate use of AR bands and monitoring behavior. Such organizations can additionally be delegated authority to purchase spectrum on competitive markets and be subsidized accordingly. While incentives to lobby for subsidies remain in such a scenario, incentives to lobby for funds necessary to acquire an expensive asset are different from incentives to lobby for retaining ownership of that asset. The relative consequence of failed persuasion is significantly lower when self-interested parties do not currently own anything that can be lost.

While the relative value hybrid forms of spectrum-management have in relation to other regimes currently hypothetical, we believe a polycentric policy framework, combined with more recent innovations in the game-theoretic modelling of sophisticated relational practices (e.g. graduated sanctioning -- see Abreu, et. al. 1987, 1990; Li and Matouschek, 2013; Li, et. al. 2017) could give policymakers the regulatory perspective and technical tools necessary to access their viability.

## 6. Conclusion and Future Research

The history of spectrum-management in the United States is interesting as it provides a clear case study documenting how drastically regulatory institutions and governance regimes can affect the growth and welfare of an industry. While much progress was arguably made in the shift from a command-and-control operational structure to a Coasian policy framework, this paper argues that policy makers should also take into consideration informal cooperation between "on-the-spot" actors (Hayek, 1945), which may be better facilitated by non-exclusive access paradigms.

More generally, we believe that insights from spectrum management can be extrapolated to consider the organized governance of resource allocation at a macro level. While the case of US

spectrum-management highlights the potential costs of centralized control and exclusivity on organizational adaptation, it is interesting to compare the case of spectrum-management with governance of another important societal resource: financial capital. Financial capital can broadly be thought of as borrowing resources from the future to promote current economic activity. Financial capital faces an intertemporal "budget constraint" in any planning problem, similar to how interference issues generate scarcity of spectrum in the short-term. In both situations, society is tasked with designing rules to allocate a scarce resource despite facing future uncertainty. Some argue that regulation of financial capital in the US has suffered from the opposite problem to spectrum management. For example, policy makers often attribute the 2007-09 financial crisis to lack of authority regulatory institutions had in controlling the growing complexity and interconnectedness of the financial system (Bernanke, et. al. 2019). Securitization of financial derivatives based on the market value of spectrum licenses seem highly feasibly and bear eerie semblance to the infamous mortgage-backed securities which were tied to the value of land rights.

Characterizing optimal balances between order and freedom has clearly never been an easy task. However, applying the theory of polycentricity to solve issues in spectrum management may be a humble step in that direction.

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