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

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Abstract Over recent decades, US spectrum policy has transitioned from a case-by-case administrative model to a Coasian one, where market mechanisms allocate exclusive yet flexible spectrum rights. This paper suggests that observing both formal and informal spectrum-management practices calls for a policy framework enabling comparative analysis across various governance structures, from exclusive access to spectrum commons. We propose an alternative framework, drawing on Elinor Ostrom's research on polycentric systems, to evaluate spectrum-sharing solutions, particularly unlicensed spectrum. Our analysis suggests that "unassigned" spectrum bands, like communal ownership or private commons within a flexible-licensing regime, can balance the trade-offs of exclusive and nonexclusive access.

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

1. Introduction

Ensuring effective transmission and reception across designated frequency bands is paramount in wireless communications, spanning technologies like Wi-Fi, cellular networks, broadcast media, and beyond. Additionally, numerous other innovations, including radar, satellites, telescopes, and IoT devices, rely on radio spectrum allocation for operation. While it's economically intuitive to share spectrum among various users given its pivotal role as a societal resource, the multitude of historical sharing arrangements underscores the complexity of allocating spectrum amidst competing demands.

In this paper, we advocate for viewing spectrum management through the lens of polycentricity, as conceptualized by Elinor Ostrom. We propose an alternative spectrum-policy framework that recognizes the value of both formal regulatory bodies, like the FCC, and informal governance mechanisms. Formal governance entails regulatory oversight to enforce contractual terms, while informal arrangements mimic social norms, fostering self-enforced sharing agreements among users.

Recent shifts in U.S. spectrum policy have moved away from rigid regulatory control towards a more market-oriented approach, granting flexible-use licenses via market mechanisms. Yet, the persistence of "unlicensed spectrum" underscores the importance of considering informal sharing arrangements alongside formal licensing. Drawing on insights from relational contracting theory, we explore how assigning exclusive property rights in spectrum can hinder productive informal coordination, highlighting the nuanced trade-offs between exclusive and non-exclusive regimes. We argue for the consideration of unassigned spectrum bands within a flexible licensing framework as a means to balance these trade-offs.

The paper is structured as follows: Section 2 provides an overview of spectrum-management evolution in the United States. Section 3 delves into formal and informal governance concepts within game theory. Section 4 outlines our proposed policy framework, while Section 5 explores the trade-offs between exclusive and non-exclusive spectrum regimes, proposing the concept of "unassigned" spectrum as a means of moderation. Finally, Section 6 offers concluding remarks.

2. Institutional Aspects of Spectrum Management

Upon its initial discovery, the electromagnetic spectrum functioned as a communal asset, where anyone with the requisite equipment and knowledge could broadcast freely. With minimal regulations and enforcement, the landscape resembled a common pool resource, as noted by Ostrom. Early broadcasters had to devise their own governance frameworks to regulate spectrum access, necessitating sharing as signals vied for space on crowded frequency bands. As broadcasting proliferated and the inherent value of radio became apparent, pressure mounted to reform the existing institutional setup.

To address this need, broadcasting entities established associations, such as the Radio Broadcasting Society in 1922, followed by the formation of the National Association of Broadcasters in 1925. These groups aimed to influence Congress to institute a more effective spectrum management system. The enactment of the Radio Act in 1927 led to the establishment of the Federal Radio Commission, later succeeded by the Federal Communications Commission in 1934. These legislative actions affirmed Congress's authority to oversee spectrum management in the public interest, promoting both commercial broadcasting and broader public spectrum utilization.

These developments aligned with Demsetz's theory of property rights and Olson's logic of collective action. The increasing value of spectrum property rights, coupled with the threat of interference to commercial broadcasting, incentivized broadcasters to advocate for formal governance structures governing spectrum access. Legal precedents, such as the Supreme Court's ruling in NBC v. United States, highlighted the chaotic nature of unregulated spectrum access and affirmed the necessity of government intervention. Broadcasters were granted spectrum access rights through mechanisms like "beauty contests," wherein the FCC determined allocations on a case-by-case basis. Additionally, the FCC assumed responsibility not only for enforcing spectrum usage rules but also for their formulation.

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 shifted from a command-and-control model to one emphasizing formal market mechanisms for allocating flexible-use licenses. These licenses grant holders the right to exclude others from their designated bands while allowing flexibility in

service, technology, and business models. This approach incentivizes license holders to create contracts with third parties, maximizing the social value of their spectrum allocation. Under this flexible-licensing regime, the responsibility for designing spectrum-sharing arrangements shifts from the central regulator (the FCC) to spectrum stakeholders (wireless carriers, TV broadcasters, technology developers). Central regulation focuses on enforcing licensee exclusion rights and terms of contracts negotiated by spectrum stakeholders.

This "Coasian" policy regime has led to widespread benefits, notably seen in the proliferation of wireless technologies since the late 1990s. For instance, the smartphone industry thrives under flexible licensing, enabling intricate contractual relationships between wireless carriers and third-party developers (Hazlett, et al., 2023). Nonetheless, there persists a call for "unlicensed spectrum" (Hazlett, 2017, ch. 16), reminiscent of early spectrum use where operators with the necessary technology could transmit freely. Several modern unlicensed bands exist within current US spectrum allocation, notably those supporting Wi-Fi networks. The rapid growth and technological advancement in the Wi-Fi industry suggest potential value in exploring non-exclusive rights regimes, such as unlicensed spectrum. The optimal utilization of non-exclusive regimes poses a significant question for regulators.

Efforts to accommodate diverse regimes within a single band are of recent interest to spectrum regulators, exemplified by initiatives like the Citizen's Broadband Radio Service (CBRS), which subdivides spectrum into tiers with varying usage priorities. International spectrum governance presents a related challenge, as radio waves transcend national borders, necessitating coordination amid potentially conflicting interests. The International Telecommunications Union (ITU), a UN agency, manages international spectrum coordination, but disputes can arise due to differing national laws and interests.

Formal vs. Informal Resource Sharing

Economists often differentiate between formal and informal governance mechanisms. Formal governance relies on a powerful third-party institution to enforce pre-agreed operational rules. The well-known Coase theorem suggests that with established exclusive property rights and negligible transaction costs, self-interested parties can negotiate efficient resource-allocation rules independently. Mechanism design offers a mathematical framework for studying formal governance rule design.

However, formal contracting can be burdensome. A comprehensive rule set must cover every possible contingency, regardless of probability, and credible implementation requires capacity for punishment and monitoring infrastructure, often incurring high costs. In contrast, informal governance operates without third-party enforcement. Agreements rely on economic actors' implicit understanding of actions and consequences. For example, diligent employees anticipate promotions and raises, while employers rewarding good performance receive quality work. When undesirable alternatives exist for both parties, cooperation based on mutual understanding fosters productive relationships. Informal agreements extend well beyond intra-firm transactions and are vital for upholding various social institutions, including the establishment of constitutions, nation-states, and centralized governments themselves (North and Weingast,

1989). They also serve a crucial role in fostering cooperation in complex environments where third-party monitoring may be too costly. In such scenarios, interacting parties can develop their own coordination mechanisms based on signals observable only within their specific action arena (Hayek, 1945).

Game-theoretic literature on relational contracting illustrates, through mathematical models, how strategic and self-interested parties can coordinate on Pareto superior equilibria in repeated interaction settings (Levin, 2003). These relational contracts can sometimes generate more social value than formal instruments (Baker et al., 1994), while poorly allocated formal property rights may undermine productive relational agreements by altering the incentives of cooperating parties (Baker et al., 2002, 2011).

Considering the economics of formal versus informal governance sheds light on inherent tensions in exclusive and non-exclusive property-rights regimes. Assigning exclusive rights to a resource can incentivize economic actors to develop complex formal resource-sharing rules and invest in necessary infrastructure for legal enforcement. However, exclusive rights may weaken incentives for cooperation in potentially more sophisticated informal agreements. Thus, the relative value of exclusive versus non-exclusive regimes depends on the preferences and monitoring capacity of the regulatory agency tasked with enforcing resource-sharing rules for a specific set of economic actors and resources.

3. Polycentricity as an Alternative Spectrum-Policy Framework

Elinor Ostrom, a Nobel Prize-winning political scientist and economist, defines a framework as a tool for identifying and understanding the elements and relationships crucial for institutional analysis (Ostrom, 2006). Frameworks provide a metatheoretical language that enables the comparison of theories and aids in policymaking by offering a concrete tool for evaluating governance structures and predicting the effectiveness of spectrum management strategies.

Initially, the perceived complexity of determining the socially optimal use of spectrum justified a "command-and-control" policy framework, where exclusive spectrum rights were solely held by the central regulator, who designed formal governance rules based on input from spectrum stakeholders. The shift to a Coasian policy framework, establishing formal markets for flexible spectrum licenses, reduced the incentives for interest groups to lobby for spectrum allocation and relieved central regulators of the burden of designing formal governance rules.

However, the success of industries like Wi-Fi highlights the potential value of non-exclusive spectrum regimes, which also align with the economic principles of relational contracting. While exclusive rights are essential for a Coasian regime, they may conflict with self-governance. Therefore, a comprehensive comparison of spectrum-policy proposals may necessitate a broader framework that considers coordination between formal and informal institutions.

The theory of polycentricity, along with its corresponding analytical tool, the Institutional Analysis and Development (IAD) framework, offers spectrum policymakers a robust means of comparing a broader spectrum of governance options. Elinor Ostrom pioneered the theory of polycentricity, which perceives communities as composed of autonomous agents who make

decisions based on both formal regulations and informal social norms. The IAD framework focuses on an "action arena" where participants interact based on formal and informal rules developed in higher spheres of interaction, which can themselves be modeled as separate yet interconnected action arenas.

The traditional view often presents the choice between an exclusive property-rights paradigm and common-pool resource management as binary. Policymakers are typically seen as either designating exclusive property rights or not. However, the IAD framework offers a more nuanced perspective. Ostrom's insight lies in developing a general framework for common-pool resource management that considers technological and human factors to determine the most suitable regime. Thus, it broadens the scope of governance structures beyond exclusive property rights to encompass a spectrum ranging from exclusive ownership to communal resource management.

In spectrum allocation, virtual parceling of the electromagnetic spectrum is often suggested as a way to implement outcomes achievable in regimes with consistent spot markets for exclusive spectrum access rights. This approach involves defining spectrum rights across observable dimensions like time, location, and transmission power. Emerging distributed ledger technologies, such as Blockchain, combined with smart contracts, can facilitate spectrum sharing among users within a frequency band (Weiss et al., 2019; Bustamante et al., 2022). Theoretically, a finely partitioned virtual space, coupled with comprehensive smart contracts, could enable Pareto optimal allocations akin to the Arrow-Debreu model of general equilibrium (Arrow and Debreu, 1954). However, creating a virtual partition fine enough to ensure full allocative efficiency is likely impractical due to the dynamic nature of spectrum uses. Moreover, implementing smart contracts using distributed-ledger technologies is still nascent, posing risks of miscoordination from poorly constructed or incomplete contracts.

At the opposite extreme lies "spectrum anarchy," characterized by the absence of formal authority to enforce spectrum property rights, allowing unrestricted transmission by any user. While this may result in the tragedy of the commons, informal coordination or relational contracting may emerge. However, historically, such arrangements have primarily succeeded in small, homogeneous communities. Considering the immense scale and critical societal reliance on spectrum applications today, introducing pure spectrum anarchy abruptly over a widely used spectrum band is likely to pose significant risks.

Hybrid forms of governance, recommended to facilitate efficient spectrum sharing, lie between these extremes. Unlicensed bands, for instance, allow usage without exclusivity but often impose formal restrictions such as power levels and equipment requirements. Overlay arrangements, feasible in flexible-licensing regimes, grant primary access rights to specified users while enabling them to grant or deny secondary users access at their discretion. The three-tier governance structure in the CBRS band is another hybrid, blending elements of unlicensed and flexible-licensing regimes. The Ostromian approach enables the study of these governance structures by examining their reliance on formal access rights versus informal coordination.

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

The historical evolution of spectrum policy in the United States illustrates the complexity and costs associated with designing and implementing flexible governance rules. Formal regulatory bodies, like the FCC, often face various obstacles, such as lobbying, information manipulation, and bureaucratic inertia, leading to inefficient resource-sharing arrangements. Deciding who should have decision-making authority over spectrum-sharing rules is therefore not a straightforward matter. Flexible licensing emerges as a logical response to these challenges, delegating the task of designing and implementing spectrum-sharing rules to self-interested parties who can better internalize the associated costs. However, formal contracts still require regulatory oversight, and incomplete contracts may result in underutilization or misallocation of spectrum.

Unlicensed spectrum is often proposed as an alternative to licensing, offering broader access and reducing entry barriers to the spectrum industry. Coordination in unlicensed bands is primarily informal, as formal regulatory bodies do not enforce private spectrum-sharing agreements. While this can reduce strategic incentives for parties to renege on cooperative agreements, open-access regimes are susceptible to the tragedy of the commons problem, leading to overuse or misallocation of resources.

Moreover, political and bureaucratic factors further complicate the effective implementation of unlicensed spectrum. Most existing unlicensed spectrum bands cannot be classified as pure spectrum commons, as the FCC imposes various usage restrictions, such as power levels and technology requirements. These restrictions strike a balance in the trade-offs associated with the allocated spectrum, limiting certain potential uses. Additionally, once allocated, unlicensed spectrum bands may be challenging to reclaim if more productive uses for the band emerge in the future. The prolonged delay in reallocating TV broadcasting bands to cellular services serves as a poignant example of how entrenched interests can hinder resource reallocation to more socially beneficial uses (Hazlett, 2017). Similar tensions are currently emerging in discussions about repurposing the CBRS band.

In recent papers, we introduce the concept of "unassigned" spectrum. In this model, spectrum is allocated to a group but specific usage rights are not assigned to individuals within that group. Instead, the band operates as a private commons, regulated by a governing body that oversees the userbase while allowing flexibility for members to establish usage rules within general guidelines. An example of unassigned spectrum is seen in bands designated for amateur radio activities, which are governed informally through constitutional rules due to the nature of open-ended services that are difficult to formalize.

A polycentric framework, treating regulators and stakeholders as autonomous agents, allows for consideration of governance structures where unassigned spectrum bands are managed by owners of flexible spectrum licenses. This approach enables private spectrum commons established by parties with direct financial incentives to manage spectrum efficiently. Alternatively, government agencies can sponsor nonprofit organizations to bid for flexible

licenses and establish unassigned bands. For instance, in amateur radio, the Amateur Radio Relay League (ARRL) sets guidelines and monitors behavior. Such organizations can be delegated authority to purchase spectrum and subsidized accordingly, mitigating lobbying incentives by dissociating ownership from lobbying stakes. While the value of hybrid spectrum-management forms remains speculative, combining a polycentric policy framework with advanced game-theoretic modeling could equip policymakers with the perspective and tools needed to assess their viability.

5. 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).

Additionally, spectrum regulation's journey highlights the complexities and challenges of transitioning from centralized control to decentralized decision-making. Regulatory shifts in spectrum management, such as the move towards flexible licensing and the exploration of unassigned spectrum, mirror transitions towards more flexible economic systems in transition economies. These transitions often involve finding a balance between government oversight and market autonomy, reminiscent of the balance between formal regulation and informal coordination seen in spectrum management. Furthermore, the transition in spectrum regulation underscores the importance of adaptive governance frameworks that can accommodate diverse needs and technological advancements, a lesson applicable to transition economies navigating rapid changes in global markets. Therefore, studying the evolution of regulatory practices for the electromagnetic spectrum can offer valuable insights into the challenges and opportunities inherent in transitioning economies towards more flexible and dynamic systems.

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