# Polycentric Governance in the US Amateur-Radio Community: Unassigned Spectrum and Promoting Open Innovation

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## Abstract

Amateur Radio (AR) is a worldwide phenomenon that has existed since the beginning of radio communications. Because it is expressly non-commercial in nature, the community finds itself challenged in explaining its value with respect to more well-defined commercial applications. We provide a case study of the US AR community, documenting the original motivations for designating the AR spectrum band as well as the community's longer-term contributions to broadening spectrum applications and training future spectrum experts.

Societal services such as AR are *open-ended* in nature, which means it is not possible to formally or contractually define the benefits society expects to derive from the service, and consequently, such services may be underprovided in traditional market economies. Our analysis suggests that the open-ended nature of the services provided by AR necessitates polycentric governance for efficient resource management, and that the current unassigned-spectrum model works well as a non-commercial alternative to excludable property rights. More generally, we argue that AR provides a valuable experimental test case for understanding how to design non-market resource allocation mechanisms for open-ended societal services.

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# 1 Introduction

Guglielmo Marconi was the first to discover how signals could be transmitted through the "ether." Today, he might be called a ham operator, or amateur radio (AR) hobbyist (Kasser 1995). In fact, the best known organization of American AR operators, the American Radio Relay League (ARRL), came together in 1914, several years before the first commercial broadcast wireless signals were transmitted from the Westinghouse Tower in Pittsburgh, and remains one of the most significant organizations of ham operators in the US.[2]

Just as ham radio operators have been around since the first radio transmissions, they have been the object of conversations about their value to society. In a sociological account of AR operators, Haring (2003) found tension in the 1950s and 1960s between those who found AR was a way to make ordinary men "freer men" and those, some of whom included the wives of the predominantly-male amateur community at the time, thought operating ham radios was escapism from family duties. More recently, questions have shifted to economic aspects of social value. AR is, at its core, non-commercial. Since the wireless crunch is driven by commercial uses of spectrum, bands allocated to amateur use are increasingly in the crosshairs of businesses and even policymakers.

One of the challenges for AR is that the benefits it provides are difficult to quantify. AR is not simply a bunch of individuals transmitting out of their backyard sheds. AR communities have their own clubs, complete with constitutions to govern members. This social capital is valuable like any other asset, but measuring it is often difficult, and simply counting the number of people who participate in these voluntary associations is not sufficient. AR also has a "technical culture" (Haring 2007); and increasingly, technical skills and a technical culture are in demand in our ever more digital economy and labor markets. However, disentangling AR's technical culture's contribution to economic growth, the upgrading of our national human capital stock, or social welfare is difficult. Finally, the economic contribution of AR operators to providing public information services in emergency and disaster situations, public announcements of community events, and other information for free that may be unavailable via other media or communication channels is difficult to assess.

Another reason to study AR is that it is an interesting and unique example of spectrum use. Unlike mobile telephony, which is clearly commercial, the uniqueness of AR's community is that the use is non-commercial by design – commercial uses are prohibited from the bands allocated to AR. Additionally, AR is non-exclusive spectrum where usage is "open" in the sense that any qualified user who abides by the governance rules is allowed to use the spectrum. In that, AR spectrum is like other unlicensed spectrum bands that have been often characterized as spectrum commons wherein users must tolerate the interference that may result from other qualified users. This is unlike the dedicated exclusively-licensed spectrum used by mobile

[2] KDKA Pittsburgh is known as first station to initiate daily radio broadcasts (and survive), but earlier stations ran previous such services. In particular, a San Jose CA station (now KCBS in SF) claimed to have initiated "radio broadcasting" in 1909. See https://sanjoserocks.org/didyou/worlds-first-radio-station/#:~:text=Doc%20Herrold%20launched%20worlds%20first,is%20now%20KCBS%20740%20AM

network operators (MNOs) or the dedicated, command-and-control spectrum allocated to government users like the DoD. Thus, AR raises important questions for spectrum management more generally, including the ongoing debates about commons versus exclusive access spectrum.

Because of the shared aspect of AR, Elinor Ostrom's research on commons governance provides a useful lens for analysis. This framework is particularly useful for rights regimes that are not readily divisible into goods that are pure public or private goods, but into goods where access and consumption may be excludable and rival to varying degrees. Ostrom suggested that for these kinds of situations, where the property is more like a commons than private property, that multi-layered polycentric governance may be effective. In general, polycentric governance recognizes a role for local autonomy that provides scope for flexible local context adjustments and can facilitate experimentation. Viewing AR through the lens of polycentric governance provides a more nuanced way to understand the various layers of governance structures that manage shared access to AR spectrum. We view that as superior to the dichotomous characterization of unlicensed commons versus exclusively-licensed spectrum that has often characterized analyses of spectrum management options. There has been an abundance of research showing that tragedy of the commons (or also anti-commons) might occur in the former approach and a deviation between private values and welfare maximizing behavior in the latter.

Under all management regimes (whether command & control, flexible exclusive licensed for mobile, or unlicensed), research has argued that inefficiencies and misallocation of spectrum resources may occur (e.g., see Hazlett, 2005; Werbach, 2011).[3] In spite of the disagreements over which regime may be best for spectrum management, there appears to be a consensus that spectrum should be managed so as to encourage more sharing of spectrum resources and so as to enable more timely adjustments of usage rights to promote allocative efficiency. In light of the technical (and business model) limitations that limited the ability to share spectrum, dedicated allocations with generous guard bands were often adopted to separate users and uses.

The growth of mobile services has increased the demand for spectrum allocated to this purpose. As opportunities for new allocations of dedicated spectrum have been exhausted, allocation decisions have often focused on identifying the highest value uses and assigning spectrum to those uses, while excluding others. Mechanisms such as incentive auctions and spectrum occupancy studies have been used for these reallocation processes. Once reallocated, spectrum management has increasingly relied on auction mechanisms to make assignments to diverse private investors. While this has been a boon for government coffers and seems to be superior to the "beauty contests" that they replace, auction approaches have recently come under attack both because they may fail to adequately reflect social values and because they may be viewed as a perverse tax on investments that are in the public interest.[4]

[3] For example, Hazlett (2005) pointed out how Tragedy of Commons (or Anti-commons) may arise in the context of unlicensed spectrum where usage rights are too widely distributed such that individual users may fail to account for the negative externalities (e.g., interference) that individual behaviors may impose on all users of the spectrum. Werbach (2011) discusses the inefficiencies resulting from the way broadcast spectrum was allocated to keep television stations from interfering with each other, but which failed to keep abreast of technology and market developments that enabled much more efficient broadcasting use of spectrum and blocked reallocation of television spectrum to more valuable uses such as for mobile broadband.

[4] Most national governments are anxious to promote investment in wireless infrastructure of all sorts, including broadband. Auction proceeds that are channeled to general Treasury coffers are a tax on the telecommunications

Advances in technology, exemplified by 5G network architectures, greatly expand the capabilities of sharing spectrum in many more ways, potentially shifting the emphasis of spectrum management away from scarcity allocation (i.e., determining which uses/users get access to scarce spectrum at the expense of other uses/users that are denied) to one of encouraging shared coexistence. There are many business models for facilitating this transition both in licensed and commons regimes, and AR provides an interesting case study for examining these issues from yet another perspective.

Our paper makes two main contributions. One is to make some headway in assessing the social value of AR, an example of an "open-ended" societal service. Our second contribution is to better understand the governance of an important example of "unassigned spectrum."[5]

## 1.1 Open ended services

Societies rely on a variety of productive services to operate efficiently. Many of these services generate a clear set of societal benefits, either in the short-run or over a specified period. When the benefits are clear and may easily be assigned to specific agents, then private property regimes and markets are often the preferred means for managing economic activity. In that case, goods and services and the property rights over the resources needed to produce the goods and services are exchanged among profit-motivated firms, investors, and end-users via commercial wholesale and retail markets.[6] When all pieces are in place, it is relatively straight-forward (in principle) to measure the value of economic activity and attribute it to specific actors by tracking their usage and payments for goods and services (e.g., as measured via the dollar value of revenues, consumer expenditures, profits, investments, etc. – data that is typically reasonably available).[7]

In other cases, however, the services are more *open-ended* in nature. "Open-ended" services are socially-productive services for which it is extremely difficult to clearly identify the benefits or assign causality or responsibility to specific economic agents for those social benefits. Open-ended services are those whose outcome distributions are too costly to feasibly specify in a formal contract that can be enforced by a trusted third party and thereby easily left to commercial market-based management. Open-ended services often include services focused on generating long-term innovations which may not be immediately observable to the public, such as pure academic research. They can also include activities focused on training individuals on how to use a particular set of resources that have a fast-evolving set of productive uses, such as the use of the electromagnetic spectrum. Governments frequently reserve dedicated allocations of productive resources for open-ended services. At one extreme are public goods where the

sector at the same time that public policies are seeking to craft government tax and subsidy policies to encourage more investment.

[5] We discuss this in more detail in Section 3.1 and in a forthcoming paper.

[6] Those transactions may be of variable durations ranging from real-time to long-term and may be viewed as contracts governing the transfer of different bundles of property rights via markets, typically in exchange for monetary payments.

[7] We say "in principle" because it is far from easy to measure social value even in near ideal situations, and determining the social value of spectrum, a basic input resource for the production of infrastructure that is essential for our economy, is far from an ideal measurement/valuation situation. See, for example, Gomez et al. (2018).

benefits produced are non-rival (i.e., sharing does not preclude the enjoyment by others, even if the benefit to others or their willingness-to-pay is much lower) and non-excludable (i.e., it is infeasible to deny users who are unwilling to pay from enjoying the benefits of the good if it is produced). Spectrum allocated to AR is not a public good in that sense, but it evidences effects that those features give rise to.

Governments also provide public funding support and preferred access to resources (including spectrum) to subsidize basic research by universities and other entities when the private incentives to undertake the R&D are inadequate. When the benefits are highly uncertain or the prospects of appropriating the benefits is in doubt, but the upfront costs of exploration (research) are (relatively) high, then market-based systems that rely on private investment incentives may fail to undertake the socially desirable activity.[8]

## 1.2 Polycentric Spectrum Governance

A key feature of polycentric spectrum governance is that it operates with more autonomy for local units (Weiss, Krishnamurthy, and Gomez 2017), as well as includes sharing and related anarchic systems to resolve and address disputes over spectrum (Bustamante et al. 2020). As we explain, the social goals and challenges that motivate the allocation of dedicated spectrum to AR fit well with the polycentric governance framework. The potential contributions of AR to innovation, wireless-tech-savvy human capital development, and public emergency and information services are difficult to value and realized over long-duration. As such, AR appears to be better characterized as an "open service" and to share features that are often used to characterize public and other government-provided (or subsidized) goods. Economists have noted that such open service goods may not be provided well via commercial market processes based on traditional exclusive/private property frameworks. We maintain that polycentric governance is valuable for managing open-ended transactions and that the AR service provides an important experimental test space for researchers and policymakers to better understand how to structure non-market resource allocation mechanisms needed to support the provision of socially valuable open services[9].

## 1.3 Organization of the Paper

The paper is organized as follows. Section 2 provides an overview of AR. In Section 3, we consider the governance of the radioelectric spectrum. Section 4 explores the value propositions for AR and highlights difficulties in governing open-ended services via traditional market mechanisms. Finally, Section 5 concludes and discusses some of the policy implications of our study.

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[8] The creation of intellectual property rights regimes for patents and copyright are intended to address the challenge confronting the creation of knowledge goods, which may require significant upfront investments that are sunk once incurred and which may be shared at minimal incremental costs. Strong intellectual property rights create a rights regime that enables market-based contracting to facilitate the appropriation of value for knowledge goods by investors in its creation, which helps solve the market-failure that might otherwise arise. Madison et al. (2009) discuss the role of government-funded basic research.

[9] A potentially interesting comparison would be to consider Citizen's Band (CB) radio. This band has much lighter licensing (mainly just registration) and was notably congested during its heyday in the 1970s (GAO 1975). A full comparative analysis is outside the scope of this paper.

## 2 A Brief History of AR

AR has a storied history. Here, we consider key events in its development, the goals of the AR community, key uses, and contributions to innovation, human capital, and emergency. This is not intended to be an authoritative history but rather to serve as context setting.

It is first useful to think about what AR operators do, and what it means to be an "amateur" operator. A fundamental characteristic of AR is that it is both a popular technical hobby and a volunteer public service.[10] AR operators used designated frequency bands for non-commercial exchange of messages, wireless experimentation, self-training, and emergency communications. Operators may contact other AR operators all over the world.

Their motivations for participating in the community of AR operators are varied. Those include the desire to learn about other cultures and to develop international friendships and collaborations, or across town, or in space (such as communicating with the space stations), or to let people know about what is happening, whether good (like a contest) or bad (like a hurricane, flood, or tornado). "Amateur" only means users that are not supposed to be using the spectrum in the exploitation of a commercial (for-profit) interest – it importantly does *not* mean that AR spectrum users lack wireless skills. Many are skilled operators. They include many uncompensated experts in the arts of wireless technologies who have contributed much to the scientific progress of radio both through their efforts as innovators and in helping to tutor and build the technical skills of new users; these new users are really amateurs in the sense that they may have rather limited technical skills (at least initially). These lay experts eventually were seen as experts (Croidieu and Kim 2018). Hence ham operators are unpaid and experts in their craft.

The origins of AR may be traced to the first signals sent by Marconi. The early radio days were largely informal, as people simply began transmitting. The formation of the American Radio Relay League (ARRL) in Hartford, CT, in 1914 was a watershed event for AR. It is a noncommercial organization of radio amateurs that has become the standard bearer for AR operators in the US. Its vision is to support the growth of AR worldwide, to advocate for meaningful access to spectrum, to get all members involved, to encourage experimentation and through its members, "advanced in radio technology and education," and to organize and train volunteers "to serve their communities by providing public service and emergency communications."[11]

As interest and wireless uses grew, spectrum management began to be formalized, as governments grappled with the challenge of managing what began to be seen as a national resource that needed to be managed to balance commercial (mostly private market) and public (mostly government) interests. Commercial broadcasters operated essentially as amateurs in so far as they had no formal licenses (Douglas 1987; Archer 1938). But unlike amateur operators in the ARRL, the commercial operators were from the outset interested in profit. The National Association of Broadcasters emerged in 1925 to lobby for broadcaster interests and pushed for the Radio Act of 1927, that played a significant role later in the design of the Communications Act of 1934 that gave rise to the Federal Communications Commission (FCC) (Hazlett 2017).

[10] AR may be the only hobby governed by both local and international treaties.

[11] ARRL's mission, vision, and history can be found here: http://www.arrl.org/about-arrl.

The FCC was designated as an independent regulatory agency with responsibility for the management of non-government uses of spectrum resources. Today, government uses of the spectrum is managed by the National Telecommunications Information Agency (NTIA), which is part of the Executive Branch, and seeks (with varying degrees of success) to coordinate with the FCC in managing spectrum use in the United States.

The principal model for spectrum management is based on the allocation of frequency bands and varies across the radio frequency spectrum, with particular bands designated for particular radio services. The AR service is defined under Part 97 of the U.S. Code of Federal Regulations. In allocating spectrum resources to the AR service, the FCC recognizes the "amateur's proven ability to contribute to the advancement of the radio art".[12] As with many other services under the control of the FCC, the operation of an AR station requires a license. For any individual to obtain an amateur license, they must pass an examination administered by a team of volunteer examiners (VE)[13]. In the US, most of the volunteer examiners are members of the ARRL.

The FCC issues six different types of 10-year licenses for AR operators, each with different privileges.[14] These licenses include the current classification of *Technician*, *General*, and *Amateur Extra*, and the grandfathered licensee classes of *Novice*, *Technician Plus*, and *Advanced* (see Table 1)[15]. As reported by the FCC, in 2022, the number of active FCC licenses held by AR operators was close to 800k (approximately 0.2% of the U.S. population[16]). Further, as it is noted in Figure 1, there are active amateur licenses in all 50 states[17].[18]

AR operators in the U.S. can use over 20 different frequency bands depending on the type of service (e.g., phone, radio telemetry (RTTY), etc.) and the type of license (see Figure 2). These frequencies range from 135kHz to above 275GHz (Radio, 2017).

Each frequency band allocated to the AR service designates AR uses as either the primary or secondary service. Secondary service users must not cause harmful interference to primary users and must tolerate interference from stations in a primary service (and from other secondary users). For example, amateur stations in the 2.4GHz band must tolerate interference from Industrial, Scientific, and Medical (ISM) equipment.

[12] It is important to note that AR operators are not limited to using spectrum that is reserved for AR use under Part 97. For example, AR operators are free to operate in ISM unlicensed bands subject to the different rules that govern those bands; and of course, many AR operators may also be employees engaged in the development, provision, or use of commercial wireless technologies or services and may spend most of their time using commercial licensed or unlicensed spectrum bands.

[13] It is worth noticing that the VEs also determine the license operator class for which an individual is qualified.

[14] *AR Service.* Retrieved from Operator Class: https://www.fcc.gov/wireless/bureau-divisions/mobility-division/amateur-radio-service/operator-class

[15] No new Novice, Technician Plus, or Advanced Class amateur service operator licenses are currently being granted.

[16] In Europe, amateurs comprise between 0.02 and 0.4% of the population, according to a recent study (https://www.youtube.com/watch?v=5Su6YCECWIEI).

[17] We can also find licenses in different U.S. territories such as American Samoa, Puerto Rico, and Guam.

[18] Retrieved from FCC License Counts: http://www.arrl.org/fcc-license-counts

| Operator class | Description | Total licenses |
|---|---|---|
| Technician | Authorized to transmit in any of the 17 frequency bands above 50 MHz with up to 1,500 watts of power | 392,880 |
| General | Authorized to transmit in all 29 amateur service bands | 186,458 |
| Amateur extra | Authorized to transmit on all frequencies and all bands | 154,757 |
| Novice | Authorized to transmit in the HF range, one band in the VHF range, and one band in the UHF range | 6,614 |
| Technician plus | Same privileges as a *Technician* plus the privileges of a *Novice* class licensee | 0 |
| Advanced | Authorized to use 275 kHz of additional spectrum in the HF bands | 35,473 |
| | **TOTAL** | **776,182** |

*Table 1 – Count of active FCC licenses held by individuals, collected and summarized from FCC files[19]*

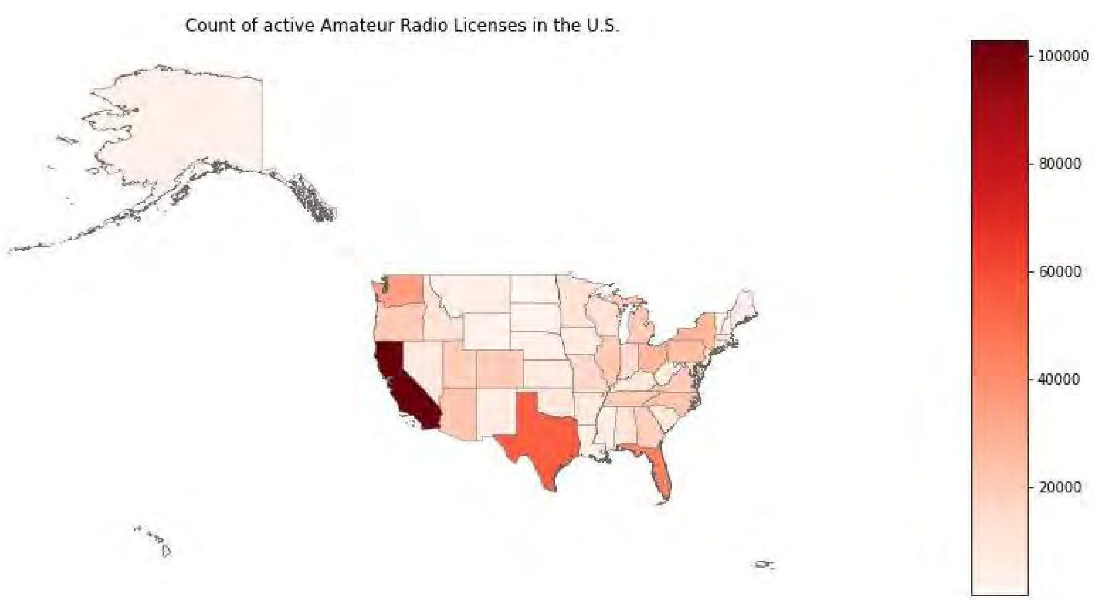


*Figure 1 – Distribution of the number of active AR licenses in the U.S. (May 2022)*

[19] Data courtesy of Keith Greiner, retrieved from https://sites.google.com/site/amateurradiodata/home?authuser=0/ on 9 August 2022. The shaded rows are legacy license classes that are no longer available, so the license counts represent this legacy and will continue to decline as licenses expire.

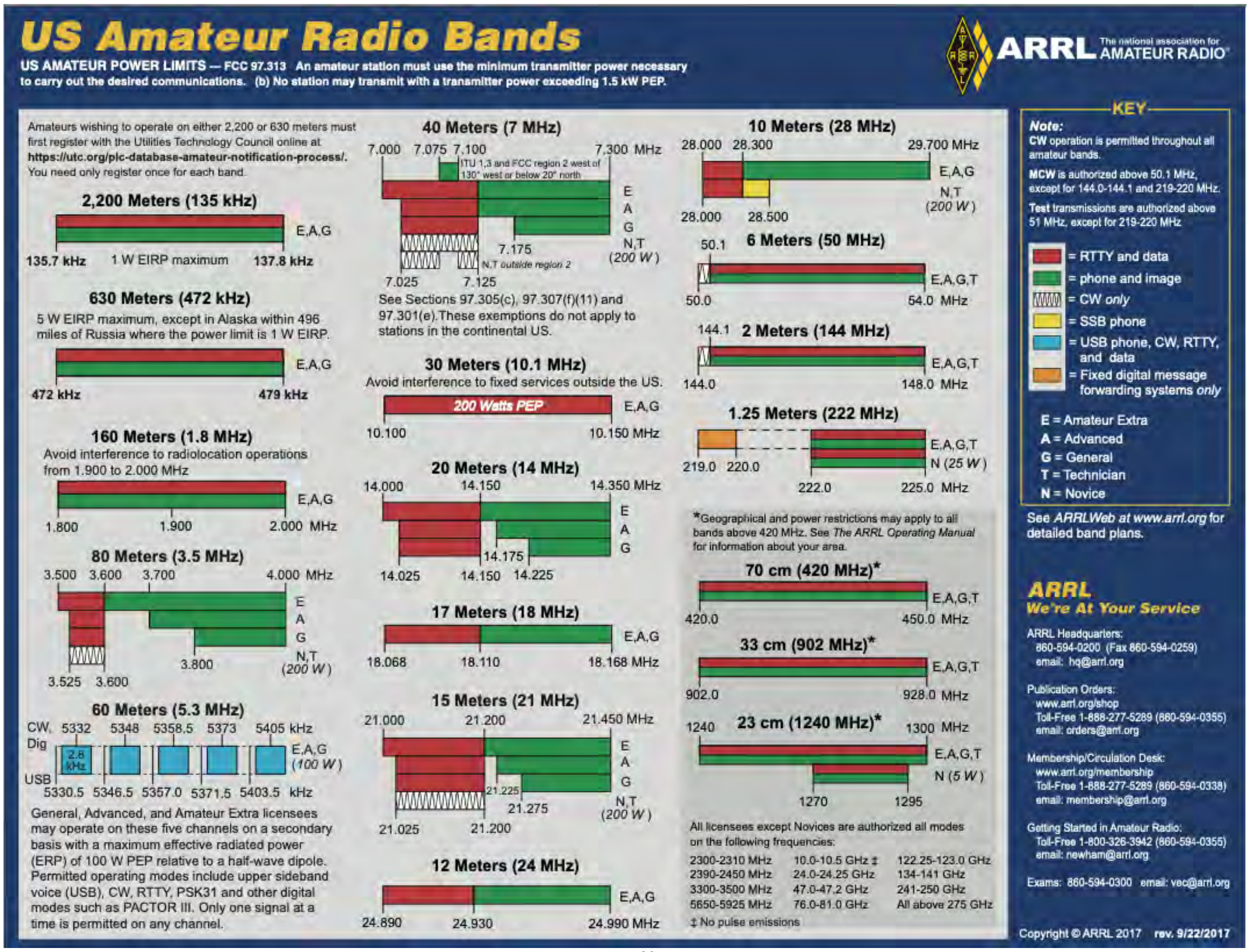

*Figure 2 – ARRL's summary of the US AR bands and power limits*[20]

As mentioned by the FCC, AR "provides an opportunity for self-training, intercommunication, and technical investigations." As Silver (2006) notes, ham radio operators and developers are often credited with inventing new wireless technologies that have resulted in unexpected commercial products and services. For instance, Slow-Scan Television (SSTV) was invented by AR operators to send pictures over regular voice radios (Westfeld, 2006), where each picture takes about 8 seconds and is sent and received by a computer with a sound card. Similarly, AR clubs contributed to the broadcast TV-style video format with the development and inclusion of the Amateur TV (ATV)[21] (Edwards, 1994). Another important AR contribution is the Automatic Position Reporting System (APRS) which serves as a way of integrating GPS position information with Ham radio. The APRS was the foundation of car theft tracking systems widely used today.

Due to the accessibility characteristics of AR, as well as its large local and international community, AR has also been used as a powerful teaching tool. The most straightforward example is to teach communications, computer science, and electric engineering (Zain 1994; Anderson 1991). However, AR tools have also been used in teaching other languages (Richmond

[20] Retrieved from https://arrl.org on 8 August 2022.

[21] It is worth noticing that both SSTV and ATV are increasingly used during emergencies.

1978), critical thinking and writing (Collins et al. 2017), physics (Bruscato and Mors 2014), and other STEM-related concepts (Lennon 2016). In addition, learning the techniques associated with ham radios has been noted as an avocational influence on the selection and development of technical careers by amateur operators.

Finally, licensed AR operators are often called upon to assist in times of crisis and emergency. FEMA supports state and local emergency response by signing and implementing a Memorandum of Understanding with the ARRL to provide for radio services during disasters, thus capitalizing on the hundreds of thousands of licensed AR operators (Coile 1997). Examples where radio operators have used their voice and technological expertise include earthquakes, fires, natural disasters (such as hurricanes, tornados and floods), parades, and even debris collection from the space shuttle *Columbia* accident.[22] The AR Emergency Service (ARES) from the ARRL is an organization that consists of licensed amateur operators who have voluntarily registered their qualifications and equipment for communications duty in the public service when disaster strikes.

The sources cited above attest to examples of how AR users and use of the dedicated AR spectrum resources have contributed to socially valuable activities that may best be considered open ended. It is not clear what might have happened had the government relied on another resource management regime to provide those goods. When the AR service and Part 97 were created, the pressure to reallocate spectrum resources to meet growing commercial demand were less acute than they have become, and the Part 97 framework that was established has been minimally changed while the technologies, markets, and innovation opportunities/challenges confronting wireless have changed dramatically. Thus, additional research to better understand the value proposition of AR and its polycentric governance regime is timely. This paper is an attempt to engage that need.

# 3 Governance of AR

As we discussed above, unassigned spectrum regimes require governance as usage grows. Consequently, it is useful to examine the governance arrangements that have emerged for AR. We describe the concept of unassigned spectrum and provide an analysis of the polycentric features of governance within the AR community. Significantly, AR in the US has multiple levels of governance – Part 97, Clubs, and Voluntary Self-Monitoring. Beyond this, there are overlapping higher-level regimes, including the FCC and International Telecommunications Union (ITU). Key challenges include promoting goals, attracting members, and enforcing rules (stopping violations, and achieving consensus).

## 3.1 Unassigned Spectrum versus Excludable Rights

Traditionally, studies of spectrum governance consider a continuum between unlicensed and licensed users. We argue (elsewhere) that AR joins a collection of other spectrum bands in a class that we refer to in general as "unassigned spectrum."(Weiss et al. 2021) Briefly, spectrum management consists of two phases: the *allocation* phase, in which a band is associated with a particular use, and the *assignment* phase, in which transmission rights are granted to a particular

[22] *Ham Radio Etiquette.* Retrieved from Ham Radio Etiquette rules: https://www.universalclass.com/articles/self-help/ham-radio-etiquette.htm

user in a time/space/frequency "parcel" of that band. Unassigned spectrum refers to frequency bands that have been allocated for a particular use but for which no assignment process takes place.

The unassigned spectrum model is an alternative to the exclusive private-property rights model that rests on a market-based reallocation of property rights to ensure socially optimal outcomes (the goal of spectrum management). As we discuss in more detail later, today's spectrum market-based solutions suffer from the fact that there are incomplete/imperfect secondary markets for certain spectrum-based services that, were they to exist, would help ensure spectrum resources continuously reflected their social opportunity cost (rather than the private opportunity cost realized by current rights holders). If perfect secondary markets existed, then an exhaustive assignment of property rights would ensure dynamic efficiency. In other words, resources would be assigned to highest-value uses and at minimum cost dynamically. Further, the assignment process would happen continuously over time and not just at the time of the auction, initial assignment, or creation of the "social contract" by which control over the spectrum use is centralized under the authority of the exclusive licensee.

In contrast, the unassigned model leaves the assignment (and control at some level) open and control subject to a polycentric governance regime. Other models, like "command and control" for basic science (satellite) and open access for Wi-Fi use, are also important. In many of these bands, most users and uses of the spectrum are not viewed as explicitly focused on commercial uses (although commercial use is not excluded). For example, the ISM bands are used by end-users for home networks, but also by commercial broadband access service providers of fixed and mobile services. Radio astronomy and other scientific spectrum users include both commercial and non-commercial (e.g., academic) research users that may be focused either on projects related to long-term innovation (e.g., basic science research) or providing services (e.g., space-based telemetry for monitoring the health of forests). AR differs from other unassigned bands. They are non-commercial by design, can involve non-local communications (at some frequencies), and can have an international focus.

While unassigned spectrum can preserve space for spectrum services that may be underprovided in traditional market environments, it introduces a new set of governance issues. First, authorized activities must be coordinated to avoid interference. Second, potential unauthorized use of the band – either by an unlicensed user or a misbehaving current licensee – generates the need for enforcement agencies. Finally, consensus must be reached among current license holders when institutional norms, etiquette practices, and/or entry requirements are generated or amended. The AR governance model is informative for its particular take on polycentric governance and the light that sheds on spectrum management (and the provision of open ended service goods by non-market or market processes) more generally.

### 3.2 Does AR implement a polycentric governance regime?

The theory of polycentricity was developed by Elinor Ostrom, winner of the 2009 Nobel Prize in Economics, to analyze the governance of the commons. "Commons" refers to resources that are jointly owned and accessible, characterized by informal and formal rules governing access, use, and trade of the resource (E. Ostrom 2010). The electromagnetic spectrum, when viewed as an input to economic production, has features of a commons: it is nonexcludable and divisible since signals compete with one another (Weiss et al. 2015).

Economic theory suggests that a lack of formal rules for users of a common-pool resource (CPR) can result in exhaustion of the resource, while rigid property-rights regimes can result in underutilization if transaction costs prevent fluid market transfers of formal usage rights (Schlager and Ostrom 1992). Polycentric governance institutions, whereby autonomous local units govern resources via informal agreements may be effective in preserving the resource while simultaneously encouraging experimentation and innovation (E. Ostrom 2012). This can be quite desirable as it enables self-correction and evolution of rules in response to emergent challenges confronting a community (V. Ostrom 1972) on a local basis. The fact that the adaptations may be "local" (in geographic, time, or some other scoping context) allows those adaptations that may not be readily observed, accounted for by more global (centralized) control mechanisms; and local agreements (consensus) may be difficult to enforce without recourse to local polycentric governance bodies.

Here, we describe governance practices observed within the AR community in the context of the theory of polycentricity. The feature categories are derived from the body of work that Ostrom and her colleagues developed in connection with studies of successful CPR governance systems (E. Ostrom 1990).

### 3.2.1 Autonomy of local units

A design feature of polycentric systems is autonomy for local units to manage resources. The autonomy of local units is what enables experimentation in polycentric systems in response to local challenges.(V. Ostrom 1972)

While unassigned spectrum is still managed by the government, there is substantial autonomy for stakeholders in these bands to develop their own rules in response to local demands, especially under liberal license policies. Local community-specific governance arrangements can evolve in response to local conditions in ways that rigid property-rights regimes cannot.

### 3.2.2 Multiple, interacting levels of rules

Another feature of polycentric regimes is the presence of multiple levels of rules. These include the "constitution" of AR (Part 97), the FCC, and informal norms and voluntary organizations.

The use of AR bands in the US is specified by the FCC's Part 97 (47 CFR 97). From a governance perspective, these rules determine technical aspects of transmission (e.g., power levels), who may transmit, and what (content) may not be transmitted. Thus, Part 97 rules function as a kind of *constitution* for the community in that it establishes terms of membership for the "club" or "society" of radio amateurs. We maintain that these usage rights also function as a constitution for the AR community (Dougherty and Edward 2011). A constitution establishes the broad parameters within which AR use is to take place and includes such important components as the identification of the value proposition that helps legitimize the allocation of public resources to the activity. In Part 97, that includes emphasizing the importance of usage being limited to non-commercial, "amateur" use.

### 3.2.3 Membership rules

Polycentric, self-governing systems require some definition of members. There is no presumption of unrestricted access to a community. As discussed in Section 2, entry into the AR community occurs through a license examination. Examinations are administered by volunteer coordinators and questions are drawn from a published pool[23]. There are three license classes available in the US: Technician, General, and Amateur Extra[24]. Each class offers a different set of operating privileges, as described in Part 97.

For example, the "Technician" license class serves today as a gateway to the community[25]. To study the role of the license in establishing community membership, we examine the license exam; the parts of its required exam are listed in Table 2. There are 35 questions on any exam: of these 9 (or approximately 25%) deal with either formal or informal governance. The category for FCC rules is the single largest category in terms of both the number of questions in the pool and the number of questions on the exam. The remaining questions are focused on "technical laws" for the hobby and serve to ensure that applicants have the operational knowledge to comply with Part 97 rules[26]. With this foundation, amateurs may diversify into different aspects of the hobby.

We conclude that a license has technical and social implications: it means that the license holder may transmit in the amateur bands, but it also means that they accept the terms of being a member of the community. Once an amateur earns a license, they have a right to transmit on the AR bands in accordance with the rules associated with their license class.

### 3.2.4 Adaptability in response to changing conditions

Changes to Part 97 can (but do not always) change the terms of membership. Changes that result in alteration of the composition of the society can be quite contentious. For example, a 2006 change to Part 97 rules that eliminated the Morse Code requirement for the Amateur Extra license class resulted in over 3500 comments to the Notice of Proposed Rulemaking (NPRM).

The Morse Code example illustrates that the unassigned spectrum requires governance, in this case, changes to the constitutional rules. The change in the rules had significant implications for the quality of AR. Though challenging to quantify, the opposition reflected a concern about the diminished value of an open-ended service.

### 3.2.5 Nested governance

Nestedness of governance in higher levels of government is a feature of polycentric systems. Polycentric systems are not free of centralized enforcers; rather, the centralized enforcers preside over the local units. With AR, there is the FCC, as well as international regimes. These international regimes are a further characteristic of AR governance.

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[23] The question pools are available here: http://www.arrl.org/question-pools

[24] Note that a three-class license structure is not universal. For example, this survey of European amateurs indicates that some countries only have one license class and others have two (https://www.youtube.com/watch?v=5Su6YCECWIEI).

[25] The exams for higher classes may only be taken in sequence: technician→general→amateur extra.

[26] We contrast this with the unlicensed usage of the ISM bands, in which case compliance with the Part 15 rules is embedded in the equipment that people use.

Institutionally, spectrum allocation occurs at the national and international levels. While most countries view spectrum allocation as a sovereign right, through treaty and practice they coordinate allocations internationally to support harmonization. International allocations are determined by the ITU. Non-governmental allocations in the US occur at the FCC (in consultation with the National Telecommunications and Information Administration (NTIA)).

*Table 2 - "Technician" examination*

| **Category** | **# Questions in pool** | **# Questions on exam** |
|---|---|---|
| FCC Rules | 67 | 6 |
| Operating Procedures | 38 | 3 |
| Radio wave characteristics | 35 | 3 |
| AR practices | 24 | 2 |
| Electrical principles | 57 | 4 |
| Components & ckt diagrams | 47 | 4 |
| Station eqpt & troubleshooting | 47 | 4 |
| Modulation modes | 47 | 4 |
| Antennas | 23 | 1 |
| Electrical safety | 37 | 3 |
| TOTAL | 422 | 35 |

### 3.2.6 Enforcement/graduated sanctions

Importantly, the FCC is the only formal enforcement agency for the U.S. AR community. The FCC has established the Enforcement Bureau (EB) to enforce all rules it establishes (from wireless to common carrier). When a violation of the Part 97 rules occurs, only the FCC has the legal authority to act. However, amateurs must compete with (monied) commercial interests for EB support in conflict resolution. In the AR bands, the ARRL, through their "Volunteer Monitoring Program" assist in the enforcement of the AR rules. In a recent study of FCC Enforcement Bureau actions, only 0.1% involved AR (Rose 2022).

Let us consider two potential violations for discussion: commercial use of amateur bands and unlicensed transmission in amateur bands (which may include transmissions by amateurs without the correct license class). Part 97 rules specify an Acceptable Use Policy (AUP) for amateur bands: that is, a description of the kind of content that may be transmitted on amateur bands. Much of this describes what "non-commercial" means. Amateur communities (as well as Part 97 Rules) generally proscribe the use of technologies such as encryption to ensure that the AUP is not subverted. Amateurs suspected of violating this policy could be subject to community sanctions as well as FCC actions. Unlicensed transmissions (AR pirates) are generally monitored through the public availability of the FCC's Uniform Licensing Service (ULS). Any amateur can examine the status of the amateur license associated with a transmission by querying the database. If the transmission is unlicensed, then community and FCC actions may be taken.

### 3.2.7 Working rules

Working rules are central to polycentric governance. To address contention and limited FCC enforcement resources, AR communities have evolved several informal governance strategies. In the US, the primary organization of radio amateurs is the National Association for AR (ARRL)[27]. There are also a large number of local clubs and associations for AR. While these do not "report" to the ARRL in a formal sense, many affiliate with it. In a similar way, the International AR Union (IARU) recognizes national bodies.

More generally, once a given AR operator obtains a license from the FCC, the question becomes how to behave. As explained by many AR organizations – e.g., the ARRL – in the AR community, members follow informal rules. In other words, operators follow conventions that have evolved.[28] These "rules of the road" range from basic principles such as tolerance, common sense, politeness, and ethics to operational rules such as when and where to transmit, station identification rules, and the ham language (e.g., the *"Q code"[29])*.

These may be considered "working rules" from the point of view of polycentric theory. For AR, these typically consist of band plans and etiquette. For example, *Band plans* guide amateurs on which frequency (sub) bands to use for different purposes.[30] However, these plans provide *guidance,* and are not *regulations,* so operators are under no obligation to comply. Similarly, the community has developed codes of *etiquette*. These are recommended behaviors that are intended to maximize the value of the AR spectrum. Etiquette has been promoted since the early days of AR.

Some of these informal rules also include enforcement procedures. Some of these are guidance from more experienced amateurs to newer members of the community. One etiquette document mentions self-appointed "frequency police" or "radio cops"[31] who take it upon themselves to enforce community standards. Smaller clubs and associations also provide guidelines and services to support the appropriate use of AR bands. These clubs often detail informal rules regarding interference resolution procedures.[32] While these processes emphasize informal resolution. If this process were to fail, some AR organizations (e.g., the New England Spectrum Management Council (NESMC)) have detailed procedures to deal with the presence of interference. This process includes a formal complaint, an investigation phase, a report of findings, an investigation response, and a resolution by an interference committee. In addition,

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[27] Previously known as the American Radio Relay League.

[28] *Connecting Hams around the world.* Retrieved from Proper communication protocol and Ham etiquette: https://www.qsl.net/ng3p/haminfo/ham-tutor/protocol.htm

[29] The *Q code* is a standardized collection of three-letter codes (i.e., abbreviations) that each start with the letter *Q* to facilitate communications between radio operators speaking different languages. Each code can be a question followed by a question mark or an answer (I4NE, 1994).

[30] The International AR Union (IARU) publishes band plans for different regions here: https://www.iaru.org/on-the-air/band-plans/

[31] These are self-appointed radio operators that are "frequency policemen who think they need to correct other hams making an error, on the air and on the spot" (Union, 2010). Most "cops" appear on DX station/DX prediction's frequency , usually when the station is working in split mode. Generally, the trigger for the appearance of "cops" is when an operator forgets to activate the split function and starts calling the DX station on their transmit frequency.

[32] *Interference Resolution Procedure.* Retrieved from Intereference Resolution Procedure: https://www.nesmc.org/docs/NESMC-IRP.pdf

the procedure establishes further actions if the problem cannot be solved within the club, such as contacting the Amateur Auxiliary[33] and/or the FCC.

More formally, the ARRL has entered a Memorandum of Understanding (MoU) with the FCC to establish a "Volunteer Monitoring Program"[34]. Under this program, operators monitor the amateur bands for violations and report them to the FCC's Enforcement Bureau for adjudication. Region 1 of the IARU has a similar program that is focused on Europe[35].

Finally, the use of *repeaters* is an important part of the amateur-radio infrastructure. Repeaters take a signal on one frequency and retransmit it on another frequency. If repeaters are well placed and designed, they allow amateurs to expand their geographic reach. They may be operated by clubs or individuals, and they may be open or closed (to non-members). The decision to build and operate a repeater is purely local and its design and placement meet the needs of the community it serves. Because of this, a geographic region may contain numerous repeaters with overlapping coverage; in other words, an amateur may be able to use multiple repeaters from their location. To ensure that the amateurs in a region can choose which repeater to use, it is helpful if the input and output frequencies of a region's repeaters are *coordinated*. To address this issue, "coordination councils" have emerged[36]. These councils work with clubs and individuals who operate repeaters for frequency planning. It is worth mentioning that compliance with the council agreements is still voluntary.

# 4 The Value of AR and Unassigned Spectrum Governance

The earlier model of "public v. private goods" was expanded upon by Ostrom (1990) when she noted that excludability/rivalry was not absolute but were boundary conditions that can be impacted by governance and context. Closely related, commons vs. markets arguments for governance overlap. In Ostrom's polycentric system, decision-making is based on overlapping but semi-autonomous institutions whose overlap relates to local decision-making (e.g., overlapping police department jurisdictions with engagement by end-users and other NGOs, which in Ostrom's richer model create the fabric of "local" – that is, *context-dependent*, which may be defined/limited by geographic scope (traditional view of local) or any other dimension on which decision-making may be localized or customized – time, context, etc.). In Demsetz (1967), a market with exclusive private property rights becomes more relevant as the size of the economy gets larger, more complex, etc., and the commons mechanism of localized decision-making no longer can accommodate the needs of specialization and decentralization of economic control.

A key challenge in the unlicensed v. licensed debates has hinged on the problem of estimating the social value of unlicensed spectrum. It is inherently harder to substantiate empirically than the social value of licensed because there are no easy to collect end-user value metrics. With licensed, although what consumers spend on cellular services and companies invest in creating

[33] An American AR organization operated by the ARRL that is authorized by and works in conjunction with the FCC (Radio, 2016).

[34] http://www.arrl.org/files/file/Volunteer%20Monitor/2019%20ARRL%20MOU%20-%20final%203-12.pdf

[35] https://www.iaru-r1.org/spectrum/monitoring-system/

[36] A list of coordination councils in the US can be found here: https://w2xq.com/bm-repeaters.html

those services is a much bigger number than the equivalent for unlicensed. However, the value of cellular is under-estimated by looking at industry revenue numbers alone. Most of the social value of unlicensed is not economically appropriated by the producers of the technology, whereas a greater share (or at least a greater absolute amount) is captured by licensed users via a market-based spectrum allocation process. In both cases, Wi-Fi and cellular increasingly complement each other and the total social welfare is greater in a world with both than it would be were we locked into or limited to a single model (all unassigned or all licensed).

The previous section showed that AR joins other examples of polycentric governance. Here, we claim that AR's societal contributions as open-ended in nature, as they focus on providing public services and investments in human and social capital that cannot be feasibly specified in formal contracts. We then argue that traditional market mechanisms are unlikely to accurately value the kinds of services performed by AR operators due to the open-ended nature of their societal innovation and training goals. Consequently, we maintain that polycentric governance is crucial for managing open-ended transactions and that the AR band is an important experimental ground for researchers and policymakers to better understand non-market resource allocation for these kinds of transactions.

## 4.1 AR's Open-Ended Services

The initial motivations for designating the AR Band focused on providing an experimental ground for expanding the breadth of spectrum applications and training future spectrum innovators. While some service providers utilize societal resources as inputs for satisfying specifically defined, immediate demands (e.g., access to the internet at a particular speed, specified entertainment content for a specific period, etc.), the nature of the societal service provided by AR operators is more open-ended in nature. Specifically, the outcome distributions of AR activities are too uncertain and too costly to feasibly specify in a formal contract that can be enforced by a trusted third party.[37] Here we discuss some general properties of AR's open-ended service contributions.

### 4.1.1 AR As a Coproducer of Public Goods

The conventional public administration approach sees crisis response as a public good provided by the government. This view has been criticized as lacking empirical realism, as many public goods are provided by citizens in response to disasters.(Boettke et al. 2007) An alternative view is that public goods are typically co-produced by government, businesses, nonprofits, and community groups.(Parks et al. 1981)

What AR does is provide rapid utilization of local knowledge. This interpretation is especially useful in considering AR. Emergency notifications are often considered a public good. However,

[37] The benefits are uncertain and likely realized over long duration and dispersed widely across society. This dispersion is due to the fact that wireless innovations contribute to the evolution of wireless networking which is basic infrastructure that is a GPT. The contributors to the innovations are also widely distributed by design. In funding research, there is a natural tension between allocating resources narrowly (more to the innovators who are expected to have the best chances of success – because of their prior records, certified skills, or other reasons that they might be singled out) and spreading them broadly (invest in lots of experiments to increase the chances of identifying successes that would be missed by the other model). The allocation of spectrum to AR as an engine for wireless innovation is clearly an example of the other model – research in breadth rather than depth.

they are not provided only by the government. But public organizations do not provide these themselves.(Olsson 2014). Since the government authorized the ARRL's AR Emergency Service, over 80,000 amateurs have registered to support responses to natural and man-made disasters.(Coile 1997). The value of these services may be difficult to quantify, but it is part of the value proposition of AR. Without AR, the government would have to invest in a more robust system of emergency notification that would provide the gap filled by amateur operators in times of crisis. It could perhaps do so, but it would be costly and not necessarily as effective as AR.

There are many specific examples, and ARRL provides information on where amateur operators were called on to address crises. One example is in connection with hurricanes: Hurricanes Irma and Jose, Hurricane Harvey, and others. With hurricane Harvey, they provided ongoing coordination in response to flooding in Texas and Louisiana.[38] More recently, Hurricane Elsa, where ARES Net was activated before the hurricane made landfall.[39]

### 4.1.2 Experimentation and Learning-by-doing

Another ongoing issue with the FCC is how to spur innovation. Dewayne Hendricks famously went to Tonga to experiment; he also experimented in conjunction with the Turtle Creek Chippewa. In both cases, Dr. Hendricks found it easier to innovate in situations where a single executive authority asserted control over spectrum management and could provide spectrum access for Dr. Hendrick's projects, unencumbered by the rigid regulatory structures imposed by formal spectrum management frameworks. Felker and Brown, writing in 1981, argue that the FCC should deregulate to provide more opportunities for amateur operators to use new technologies, as well as deregulate restrictions on AR repeater operations and CB licensing (Felker and Brown 1981). They also included recommendations to strengthen AR's technical orientation, allowing amateurs to operate at more frequencies, and explicitly recognize recreational and hobby uses for personal radio.

A defining feature of AR is pushing boundaries, including launching AR satellites in the early 1960s, shortly after the first satellites were launched by governments.(Wait 2015) Another value of AR is honing engineering techniques. As Caverly et al (Caverly et al. 2015) note, AR communications predated the formation of the Microwave Theory and Technology Society (MTTS) (now, IEEE MTT-S). It was the ARRL that published Two Hundred Meters Down, a key development is the use of wavelengths less than 200 m (1.5 MHz and above). AR has been described as a "harbinger" of Sputnik in the USSR.(Bulkeley 1999)

AR also contributes to human capital formation. It does so through learning by doing. These are portable skills that can be taken. Unlike private firms, where this is a positive externality and underprovided, the skills developed in AR communities are investments by individuals. Having a pool of "wireless" technology-educated workforce and consumers benefits from opportunities to hone those skills. The detailed skills exemplified by amateur users will be shared only by a small fraction of the general population.

[38] http://www.arrl.org/hurricane-harvey-response

[39] http://www.arrl.org/2021-hurricanes

The benefits of this are externalities (or spillovers). Those skills-related social spillovers/externalities vary significantly in the extent to which they are privately appropriable. Some socially valuable careers are sufficiently privately valuable that market-based processes can ensure adequate private incentives exist to pursue those careers (although public subsidies/interventions may still be needed to address bottlenecks – e.g., data scientists in particular and STEM-educated more generally today); whereas other careers (like criminals or public school teachers) may require more public governance intervention to steer incentives and supply of those skills in ways that promote (retard) socially beneficial (harmful) externalities.

Long-term innovation is intimately related to human-capital formation since building the right labor force/end-user skills/capabilities is a key enabler of future innovation. In that sense, it is like a GPT for innovation – it is not about a specific innovation for which the future economic impact (social or private) may be anticipated and hence for which market-based allocation processes are most easily applicable; rather, for potentially unforeseeable innovations. For example, basic science (astronomy) or other "foundational" technologies (as opposed to merely disruptive technologies).

Additionally, AR constitutes a community. This is unlike most commercial uses of radio, which provide a service on a profit-maximizing business model. Sociologists refer to this as social capital.(Granovetter 1977) Social capital is an asset of communities much like any other.(Putnam 1993) Dividing up AR would likely have the cost of reducing social capital in communities. Measuring this social capital is challenging. In *Bowling Alone* (2000), Putnam provides a simple measure: how many people still participate in clubs? The title of the book refers to the decline of bowling clubs. AR, by this simple metric, is generating value as social capital: there are lots of people in the clubs, and they transmit together, in communities.

## 4.2 Market Failure and Open Innovation: The Valuation Problem

A common governance strategy for efficiently allocating resources across societal services is having a government-empowered regulator. In spectrum, the FCC has taken a market-oriented approach for many active spectrum uses. In this approach, they seek to clearly delineate property rights over resource usage and enforce the terms of formal markets for transfers of those rights whenever needed. When a rich enough set of contracts over property-rights transfers and desired services can be written and "sold" at competitive rates, efficient outcomes are predicted by standard economic theories. It is thus not surprising that the observed price of commercial services is often used as a benchmark for computing its societal value. In an environment in which complete and competitive markets for both property-rights transfers as good services can exist, the necessity of non-market governance would indeed be questionable.

However, in all actual economies, fully complete and perfectly competitive markets for property-rights transfers and services based on complete contracts do not exist. Some richly studied tensions include:

- the presence of market power, or the ability of service providers to engage in privately-rational behaviors that may reduce aggregate welfare such as by setting prices too high or engaging in strategies to raise rivals' costs;
- asymmetric and imperfect information and the lack of mechanisms to enforce contractual agreements when private deviations are optimal;

- matching problems due to non-convexities due to technological or other environmental factors that preclude matching supply and demand.

In light of these challenges, market-based exchange of exclusive property rights will not be sufficient to ensure dynamic, allocative, and productive economic efficiency. This is especially true when one adds in the desire to promote social goals (distributive) that select among efficient outcomes, or that sacrifice overall efficiency in favor of accomplishing normative goals (e.g., universal service goals, equity, and inter-generational utility maximization[40]). Generating complete markets for transferring resource-usage rights has also proven to be difficult, especially in the case of spectrum where vested interests in status quo allocations conflict with policy reforms conducive to making market-based spectrum allocation more efficient. Furthermore, the fast-evolving nature of society's demand function for spectrum-based services would intuitively require consistent spot markets for trading a wide array of spectrum – capabilities that do not exist yet (Gomez, Weiss, and Krishnamurthy 2019).

Under-utilization of a resource (or more generally, resource misallocation) arising from inflexible property rights regimes has been dubbed the "tragedy of the anticommons" by academics. The friction complements the more familiar "tragedy of the commons" which occurs when exclusive rights over a resource are not well defined and the resource is overused (or more generally misallocated) (Hazlett 2005). Ironically, it has been noted that attempts to prevent the tragedy of the commons often spur the other tragedy. In the case of spectrum, various solutions have been proposed to strike a balance between the two tragedies. These include finer virtual parceling of the electromagnetic spectrum into smaller commoditized pieces, as well as spectrum-sharing arrangements, which delegate the responsibility of resource allocation to stakeholders in the spectrum-service community and can allow for a more flexible set of marketed usage rights.

For open-ended services – such as AR's innovation and training initiatives – the difficulty in describing intended outputs challenges market-oriented allocations of spectrum resources even further. While commercial service providers often utilize societal resources as inputs for satisfying specifically-defined, immediate demands (e.g. access to the internet at a particular speed, specified entertainment content for a specific period, etc.) details for open-ended services are harder to specify in contractual form. There may be an inability to forecast exactly what realized output society can expect from the usage of the resource. Furthermore, even if a distribution of potential outcomes could be identified, there may still be significant uncertainty in the length of time needed for the open-ended service to even begin generating an observable output. In the case of spectrum, AR activities often lead to highly unexpected innovations which take years or even decades to reach commercial use.

The tension of incomplete contracting over open-ended services is hard to resolve as it typically stems from technological constraints imposed on economic operations. For example, third parties may be unable to cost-effectively monitor actions or observe all pertinent information. A

[40] A fundamental challenge society confronts is the balancing of the interests of current users against past and future generations. Even of one ignores any debt we may have to the past, the interests and values of future generations are unknown. Debates over the value of reserving spectrum resources for basic research versus mobile broadband services that today are mostly spectrum starved because of the need to accommodate streaming entertainment video are an example of this challenge.

consequence of this is that even if we could isolate a portion of the underlying resource to be reserved for open-ended services, implementing a market mechanism within that restricted community would still generate resource misallocation relative to the optimal outcome. And, there would still be the challenge of how to manage access to the community when a key goal is to ensure access aspires to openness. Consequently, governing open-ended services via market mechanisms can result in a variety of market failures and the under- or over-provision of the desired social goods.

Nevertheless, the congestion features of spectrum mean that AR governance is required, much like any commons. We argue that, given the advance of ICTs, exclusion-based market regimes are not the only solution to managing open innovation. One way we deal with complexity in today's hyper-connected/integrated, ICT and increasingly wireless world is by enabling "localized" (customized to the context) decision-making. This calls for complementing private property-based market mechanisms for resource allocation with other models, like unassigned spectrum. It is not a "one or the other" binary choice, but a range of options between these extremes.

An intuitive non-market option is to identify a collection of service providers who are willing to engage in desirable open-ended activities for minimal pecuniary compensation, designate a portion of the resource for those providers only, and allow this specified community to reach their agreements on how to allocate their portion of the resource. A central regulator with limited monitoring and enforcement authority could be involved, but the terms of its involvement must be agreed upon by the community. In this regard, the US amateur-radio community can be viewed as an experimental group for learning how to design and implement this polycentric form of non-market governance for allocating resources to open-ended services.

# 5 Conclusions

AR, with its long history and substantial impacts on society, is largely under-studied from the perspective of telecommunications policy. While this paper contributes to that area, there are larger policy impacts that we would like to draw out.

We have argued above that AR is an example of unassigned spectrum, and that unassigned spectrum requires the development of governance to manage problems of congestion. We have also argued that the governance mechanism of AR fits the polycentric model that was developed by the Bloomington School and inspired by Elinor and Vincent Ostrom in their groundbreaking body of work. These points have some particular implications that are relevant to policy going forward. Notably, at the Federal level, a recognition that the Part 97 rules function as a constitution for the AR community could guide the posture of rulemaking. Constitutional change can have an impact on the shape and character of the community and the FCC may be able to make better policy if it recognizes this aspect of its rulemaking procedures and engages the community appropriately from this perspective.

The other key point that we would like to highlight is that AR serves not only as a laboratory for technical innovation and a platform for the development of human capital but it also serves as a laboratory for *institutional innovation*. AR has developed institutions to address various challenges, including frequency coordination, etiquette development, and self-enforcement. As technology has evolved, so have the institutions that have emerged (see, for example, the emergence of repeaters). For policymakers, one of the useful questions is *what can we learn from AR that can be applied to other instances of the unassigned spectrum?*

For example, the FCC is currently considering revised rules for the Non-Geostationary Orbit/Low Earth Orbit (NGSO/LEO) satellite systems (Berry et al. 2022). These systems operate on an unassigned spectrum model as well. The rules being developed include an automatic band segmentation (the "1/n rule") to deal with inter-system interference should it occur if operators are not able to coordinate. The AR community has dealt with similar problems for a century and has developed durable institutions to address them. So, a useful question for the FCC and for the NGSO/LEO operators is: is there anything that satellite operators could learn from AR that could lead to efficient coordination?

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