Coase and WiFi: The Law and Economics of Unlicensed Spectrum

BY DOUG BRAKE | JANUARY 2015

"It is sometimes implied that the aim of regulation in the radio industry should be to minimize interference. But this would be wrong. The aim should be to maximize output."– Ronald Coase, Federal Communications Commission, 1959.

In 1959, economist Ronald Coase argued for innovative and needed change to the system of spectrum allocation, challenging the prevailing "command and control" model in favor of one based on property rights and auctions. Today, many continue to not only rely on Coase's insights to support spectrum auctions over command and control, but also invoke Coase's writings as almost sacred texts opposing any use of spectrum for unlicensed purposes. We believe that this is a simplistic and inappropriate reading of Coase and that his economic insights provide strong support for unlicensed, as well as licensed, spectrum. Indeed, Coase was primarily attacking a model of governmental command and control that was in dire need of modernizing. But Coase surely never intended his work to be used to support rigid and doctrinaire thinking about spectrum.

This paper examines the support for a new interpretation of Coase, concluding that a mix of both unlicensed and licensed spectrum is well grounded in Coase's economic pragmatism. There is a wide range of possible ways to define rights in spectrum use; we should craft those rights in such a way that minimizes the costs of arranging the most socially beneficial outcome. Given the tremendous benefits of both licensed and unlicensed applications, we need a spectrum policy grounded in Coasean pragmatism, not Coasean doctrine.

When Coase changed the thinking of spectrum policy, it had been well established that some mechanism was required to sort out the "etheric bedlam"[1] of radio interference. The 1920s saw an explosive growth of radio broadcasting as a form of entertainment and information. With that growth came significant interference problems, leading the government to begin coordinating spectrum use in a top-down fashion to minimize interference.

Coase saw that government command and control is generally not the most efficient way of allocating scarce resources and pushed for the introduction of property rights and a pricing mechanism in spectrum allocation. However, when Coase wrote this work, wireless technologies that operated over very short distance were a very small niche. So what would Coase have said about spectrum policy in a world of much more diverse wireless technologies and applications? Today, unfortunately, like so many areas of communications policy, spectrum policy has become increasingly polarized, with one side arguing against property rights and for virtually all spectrum to be in a commons (e.g., unlicensed) and another side rejecting unlicensed and favoring virtually all spectrum being auctioned. And these latter advocates call on Coase for intellectual support for their position. We believe that Coase's underlying reasoning supports a mixed regime of spectrum rights (some licensed and some unlicensed) to maximize productive output.

A BRIEF HISTORY OF UNLICENSED RADIO

In the beginning, all radio use was unlicensed. The first uses of radio waves were entirely unregulated, and everyone was free to make use of the spectrum as they wished. The most prevalent early radio use was for ship-to-shore (and shore-to-ship) communications.[2] For a while, there were so few people making use of this novel technology that spectrum was abundant. But, as radios became more prevalent, problems began to arise – where two radios attempt to communicate using the same frequency at the same time in the same space, the receivers essentially get confused, resulting in interference.

It is often said (though the story is somewhat apocryphal) that rescuers had difficulty finding the sinking Titanic because of interference.[3] No doubt, this early history was a time of chaos, with operators blanketing large areas with high-power signals without a mechanism to coordinate against interference. After an initial, failed attempt to regulate radio,[4] the problem of interference became especially acute with the rapid growth of broadcasting in the late 1920s, prompting Congress to create the Federal Radio Commission.[5] With 1934 came the Communications Act, which established the Federal Communications Commission and gave us the basic structure of the communications laws we have today.

Coase's work on radio regulation, coming twenty-five years after the establishment of the FCC, has had its largest impact in how the Commission assigns licenses to operate on a given range of frequencies. When Coase was writing, the Commission assigned licenses through comparative hearings whereby an administrative judge would decide who would put the license to the best use.[6] Coase saw this was no way to allocate a resource, even, or

especially, a scarce one.[7] Normally we rely on a pricing mechanism and markets to ensure that scarce resources go to those who believe themselves able to generate the greatest value.

Eventually, though it took some 67 years,[8] Coase's argument was finally heeded, and in 1993 the Omnibus Budget Reconciliation Act gave the Commission the authority to use a competitive bidding process – an auction – to assign mutually exclusive licenses. The Commission then began auctioning licenses in earnest, holding six different auctions from 1994 to 1996.[9]

But not all radio use is "mutually exclusive" requiring an auction. Unlicensed spectrum allows unregistered users to operate radio devices without first obtaining a license. Instead of a license, the Commission uses technical restrictions and device certification to help limit interference between the wide varieties of uses. Although a far cry from the intensive use of unlicensed devices of today, the Commission saw the need for this class of radio operation quite early.[10] In 1938, soon after the FCC itself was established, the first unlicensed rules were created, with wireless record players being the "killer app" of the day.

The key difference between licensed and unlicensed spectrum is the right to protection against interference. Under the Part 15 rules, unlicensed devices are not guaranteed any protection against interference and cannot cause harmful interference to any licensed service.

Some have wrongly decried such a regime, claiming that without protection against interference, unlicensed spectrum would see a free-for-all of over-use, ending with a "tragedy of the commons." Although we are certainly approaching the capacity of existing unlicensed allocations, and interference is a concern, unlicensed spectrum has been far from tragedy. Recent studies have estimated the total economic value of U.S. unlicensed spectrum at over $220 billion.[11]

For years spectrum policy has been mired in a debate over what model would best serve the United States. Strong believers in free markets push for exhaustive licensing of exclusive, flexible rights in spectrum, while believers in more communal economic arrangements want to avoid property rights in favor of a more open licensing model. Both sides believed their model best at maximizing the economic value of spectrum.

This so-called "great spectrum debate" is on great display in a 2002 report from the FCC's Spectrum Policy Task Force.[12] The Task Force's report signaled a decisive shift away from traditional command-and-control allocations toward more flexible uses of spectrum. Over the summer of 2002, the Task Force's large group of spectrum experts developed a broad set of recommendations with a particular focus on two new spectrum rights models: exclusive rights and "commons" or unlicensed.[13] On the establishment of the Task Force, then Chairman Michael Powell remarked,

> *The government has an almost impossible task trying to keep pace with the ever increasing demand for spectrum. . . . In this fast-moving world, the Commission cannot rely on outmoded procedures and policies. We must establish new ways to support innovation and the efficient, flexible use of spectrum.*

For too long these two models, exclusive rights and unlicensed, were presented as an either/or decision. Advocates on each side were purists, believing that their model could do all the work of the other, with advocates of a licensed-only approach citing Coase to support their view. An optimal system is one that leverages both models, recognizing the unique contributions of each.

Oversimplification misses the careful nuance of Coase's work on externalities, under-estimates the productive efficiencies of a well-designed unlicensed allocation, and ignores the value-enhancing negotiations and localized problem-solving Coase would celebrate that take place within unlicensed bands.

WHY DO WE CARE WHAT COASE THOUGHT?

It may seem strange that we still concern ourselves with the ways in which a particular 55 year old text may be read. Why do we care what about one economist's abstract theorizing from half a century ago? In a very real sense, we don't. We simply want the right policy, the policy that drives productivity and economic growth throughout the ecosystem enabled by radio spectrum. And in that sense we shouldn't consecrate half a century old texts, especially where technological possibilities have advanced dramatically. Policy debates should reflect current thinking and current realities.

At the same time Coase's insights and influence are difficult to overstate. By most estimates his paper *The Problem of Social Costs,* which generalized and expanded the arguments he presented in *The Federal Communications Commission*, is the most cited law review article of all time by a wide margin.[14] However, there is a real concern that Coase's writings, influential as they are, have been over-read. Many continue to interpret his work as fully supporting a regime of purely exclusive spectrum rights without appreciating its nuances or historical context.

George Mason's Thomas Hazlett, for example, has long been a prominent advocate for the superiority of exclusive spectrum rights over other all models, pointing to Coase as the father of auctioning exclusive rights.[15] Hazlett has done much to elevate the debate around spectrum rights, but the thorough "propertizing" of exclusive spectrum rights defined through frequency boundaries he argues for goes beyond Coase's careful empiricism.[16]

With Coase's broad circulation and name-brand recognition comes a risk of oversimplification. The thinking goes something like this: "Coase was for property rights in spectrum, Coase is widely respected if not idolized, therefore an exhaustive auctioning of exclusive spectrum property rights must be the way to go." This oversimplification misses the careful nuance of Coase's work on externalities, under-estimates the productive efficiencies of a well-designed unlicensed allocation, and ignores the value-enhancing negotiations and localized problem-solving Coase would celebrate that take place within unlicensed bands.

Indeed, a lot has changed since Coase's early work on spectrum. His focus then was on improving the efficiency of allocation when the use case for radio technology was predominantly audio and video broadcasting. We now have a wide range of uses for radio spectrum that require a variety of different architectures and designs. Wireless policy should move beyond the narrow focus on allocative efficiency of a single input (spectrum) and consider the broader ecosystem different regimes enable through empirical analysis.

The argument advanced here is that Coase's writings support a combined licensed and unlicensed regime to minimize transaction costs for a variety of radio architectures. Grand pronouncements of "spectrums commons" or "licensed-only" do nothing to advance the kind of nuanced, careful analysis needed.

COASE'S PRAGMATIC INSIGHT

Coase was no ideologue.[17] An ideologue would not have argued as Coase did that some kinds of externalities, like that from air pollution –what he called smoke – required a regulatory, not market solution. Coase wrote:

> *When large numbers of people are involved, the argument for the institution of property rights is weakened and that for general regulations becomes stronger…. if there were only one source of smoke and only one person were harmed, no new complication would be involved… But if many people are harmed and there are several sources of pollution, it is more difficult to reach a satisfactory solution through the market.*[18]

He went on to note in these kinds of situations "the process of negotiation may be so difficult and time consuming as to make such transfers a practical impossibility." This is quite similar to the situation with unlicensed where there are so many devices (the millions of baby monitors, garage door openers, WiFi routers, etc.) that negotiation with spectrum owners becomes a practical impossibility.

Coase's pragmatism may come as a surprise to some – his thoughts, serving as the foundation for the law and economics movement, have long been used to support an increased, if not thoroughgoing, reliance on private transactions. Coase's early work was a tremendous contribution to the subject of externalities – in his words, problems of reciprocal "harmful effects."[19] Externalities are an economic concept where production affects a party who did not choose to be involved in the production. These "spill-overs" can either benefit (positive externality) or harm (negative externality) another party.

The policy goal when it comes to negative externalities is not necessarily eliminating them altogether but ensuring that the costs associated with them are allocated appropriately. Coase's insight was that in many instances, the parties themselves can discover the most economically efficient way to solve a problem from negative externalities without a rigid, up-front assumption that the party "causing" the problem is to blame.

Put simply, Coase recognized that when it comes to these types of problems, it takes two to tango – an externality is only a problem if there is another party who is situated in such a way to be harmed. It can be difficult to cleanly disentangle who is at fault for the harm, and, at times, our moral intuitions and linear understanding of causality can lead us astray from optimal arrangements.

Through a number of colorful examples, Coase illustrated that we shouldn't automatically assume that the onus of minimizing negative externalities should be placed on the entity doing the producing. The burden of avoiding harm should generally be with whoever can avoid it with the lowest cost, consistent with non-economic concerns. The important point is that if we allow flexibility in the system, independent actors can, in many situations, find better solutions than rigid rules.

Reading Coase as supporting property rights and private transactions in spectrum is certainly not misguided: in his famous paper, "The Federal Communications Commission," and elsewhere[20] Coase was quite clear in his advocacy for property rights in spectrum. But remember that Coase was fundamentally arguing against a rigid command and control model of allocating spectrum in an era when a single radio architecture, broadcast, dominated. Much has changed in telecommunications since the 1950's; we should be guided not by the specifics of Coase's work against the command and control regime of the time, but his more general, empirical analysis of the transaction costs of allocating negative externalities in the form of interference.

A myopic focus on the rights to spectrum in-and-of itself misses out on the transaction costs of repurposing radio equipment. What we care about are markets driving efficient use *of spectrum, not simply efficient allocation of spectrum in the abstract.*

When the subtle insights of Coase's pragmatism are boiled away – his careful historical study simmered down to a one-line theorem – it is easy to lose sight of his fundamental pragmatic insights. Indeed, much has been made of the Coase "theorem." The theorem, promoted by George Stigler (but actually disavowed by Coase himself), goes something like this: in a world without transaction costs it doesn't matter where you put the liability for negative externalities like pollution, for example, because the right to pollute will eventually end up with whoever values it most.[21]

Such a formulation hides an important point: transaction costs are usually high and the initial allocation of rights matters quite a lot. A persistent, misleading characterization of spectrum as real property exacerbates this sleight of hand. A myopic focus on the rights to spectrum in-and-of itself misses out on the transaction costs of, for example, repurposing radio equipment. What we care about are markets driving efficient *use* of spectrum, not simply efficient allocation of spectrum in the abstract. The initial allocation of rights, however defined, has a profound effect on the structure of and architecture of a particular radio service.

However, the "theorem" formulation – low transaction costs plus well-defined rights equals efficient outcomes – clarifies the two general approaches for policymakers to attack negative externality problems. One can economize on transaction costs and/or clarify the definition of rights.[22] Obviously, work in both areas is good, but there is no reason to think that one single rights definition or level of transaction costs that is ideal for all situations.

Coase's pragmatism is perhaps best captured in the following quotation from his *The Federal Communications Commission*: "It is sometimes implied that the aim of regulation in the radio industry should be to minimize interference. But this would be wrong. The aim should be to maximize output."[23]

This maximizing of output, is fundamental, both as goal of policy and as a methodology. But what exactly does this mean in the context of radio policy? What does it mean to maximize output in this context – what do we want to maximize?

MAXIMIZING RADIO OUTPUT

It is not immediately obvious what the "output" is that we want to maximize: is it simply maximizing the allocative efficiency of spectrum bands, perfecting the mechanisms allowing spectrum to flow to the "highest and best" use?[24] Is it the number of spectrum transactions on the secondary market? Economic value of licensed spectrum uses? Auction

revenue? Consumer surplus? Overall capacity in wireless networks? Productive efficiency? Putting spectrum to use as much of the time as possible?

We care about each of these measurements in different contexts, and there are different situations where we might want to maximize the value of a particular band for a single licensed use or maximize the total throughput, for example. But how we go about this?

Spectrum is a peculiar resource, if it can even be called a resource at all.[25] It is infinitely renewable, divisible in 6 to 8 dimensions,[26] and unused spectrum is wasted opportunity that can never be recaptured. Although technology is progressing to make radios more flexible and adaptable in real time,[27] most radios, and especially radios designed for the consumer mass-market, are built for particular purposes and particular bands. When it comes to spectrum, we are not dealing with the type of resource that can be easily commoditized and transitioned from use to use. Indeed, the cost of repurposing a particular spectrum band can be very expensive.

The architecture of a radio system using a particular band (and in turn the output it potentially maximizes) depends on a number of different factors. Of course, limits the Commission puts on a particular allocation have a significant impact. For example, limitations on power levels, the band plan, geographic location and granularity of licenses, not to mention explicit service restrictions, have a large impact on the possible architecture of a particular radio service.

Of course the Commission does its best to match these rules to the valuable uses of the day and has also made strides in allowing more license flexibility and trading to allow the market to guide the way to more valuable uses. But the point is that we are already far from ideal Coasian bargaining with flexible licenses and auctions alone. We are forced to make judgment calls on appropriate rights definition, in terms of service rules and band plans.

Beyond the technical rules on spectrum, a number of other inputs shape the economic possibility of a service. The radio equipment itself plays a huge role in the economics of a service offering. In the mobile broadband context, scale is the name of the game, with global economies of scale in devices driving international harmonization of spectrum. Other, more niche services, such as those for various military applications, require specialized devices where economies of scale are not as important.

Market mechanisms absolutely go a long way when it comes to allocating spectrum. Continued liberalization of licenses and trading through secondary markets, for example, should certainly be encouraged. But, for better or worse, we will continue to need upfront judgment in setting the terms for how the market operates. Once we broaden our thinking beyond spectrum as a commodity and think more in terms of a market in rights to use radios in particular ways, it becomes clear that a definition around the ability to exclude is one of many decisions we must make, and perhaps not even the most important one. Also note, once we are at this point, thinking of rights to utilize radios in particular ways, it becomes clearer that excludability need not necessarily be defined in black and white terms. Indeed, complete excludability (licensed) and the complete lack to a right against

interference (unlicensed) represent only the extremes of one axis along which radio use is defined.

The limitations placed on unlicensed bands to minimize the likelihood of interference have long been touted as a way to minimize transaction costs.[28] Indeed, by making access to spectrum virtually free to the end user, one can, for example, blanket their home or business with WiFi access for only the cost of equipment. Auctions of exclusive rights (however defined) absolutely make sense for any service that expects a high degree of reliability or requires a large investment. But in a world where we have moved beyond broadcast and have begun watching video streams on tablets, unlicensed spectrum is an excellent way to maximize output by minimizing transaction costs.

Coase was in fact remarkably clear that minimizing the risk of interference can be done through delimiting rights either through markets or through regulation, and that, as he puts it, "[h]ow far this delimitation of rights should come about as a result of a strict regulation and how far as a result of transactions on the market is a question that can be answered only on the basis of *practical experience*"[29] (emphasis added). The key point that Coase was trying to make, is that the answer is almost certainly not purely through regulation, but, for that matter, may not be purely about markets either.

THE EMPIRICAL CASE AND RECOMMENDATIONS

Coase was writing at a time when there was no real option for a functional unlicensed ecosystem. In 1959, when Coase was first articulating these ideas, we were dealing with a small set of possible architectures (satellites were just being introduced). Now with advances in technology it is possible to have a thriving market in unlicensed devices. A key change since 1959 is the number valuable unlicensed architectures that emerge by virtue in changes in the surrounding technology unlicensed devices are enmeshed in. The possibility of maximizing valuable use of radio spectrum through a larger number of low-power, low-transaction cost devices scattered throughout the country should not be underestimated.

This is a theoretical way of making an obvious point: unlicensed is better at maximizing output in a world where extensive last-mile access networks can easily interact with popular devices that use high-value unlicensed protocols like WiFi and Bluetooth.

To be clear, one can wholeheartedly agree that the particular limitations the FCC puts on unlicensed use, or even the process of making those decisions, represent a lost economic cost. But that cost allows for users to access the radio spectrum at near-zero transaction cost. In particular, the combination of cheap radios and pervasive wired networks make it easy to expand access in valuable ways. Agreed, there is some hidden overhead in process of designing the operating rights to minimize interference, but this is undoubtedly outweighed by the considerable economic value of unlicensed operations.[30]

The empirical case for unlicensed is quite strong. It is difficult to evaluate the total economic value of unlicensed spectrum, but recent estimates have put it on the order of $140 billion.[31] Indeed, this is far from a tragedy of the commons. Beyond the unlicensed uses of years past - things like garage door openers, baby monitors, and cordless phones - recent unlicensed protocols have seen an explosion in use. WiFi, of course, is the obvious

example. Consumers rely on WiFi daily, utilizing it for seamless connectivity throughout the home and workplace. Other protocols like Bluetooth also serve as key platforms for innovative products and services.

Furthermore, unlicensed spectrum will play a key role in connecting the Internet of Things (IoT). There are a host of protocols available for different IoT applications. ZigBee and 6LoWPAN are good examples of developments that will allow tiny, power-sipping devices to connect with the rest of the world. Some RFID technologies also rely on unlicensed spectrum, although RFID's success is perhaps not as well known as it is utilized more in business logistics and consumers do not frequently interact with it.

The 802.11 family of WiFi standards in particular have seen remarkable success. WiFi utilizes listen-before-talk mechanisms to enhance the value of unlicensed spectrum for all users. This is a key point: to the extent technology itself can realistically take over the job of mitigating interference, the empirical case for unlicensed becomes stronger.[32]

The empirical case for unlicensed is quite strong. It is difficult to evaluate the total economic value of unlicensed spectrum, but recent estimates have put it on the order of $140 billion. Indeed, this is far from tragedy.

Although there is some evidence we are approaching maximum capacity of unlicensed spectrum,[33] WiFi protocols do much of the heavy lifting to coordinate simultaneous access to spectrum. This introduces some limited over-head, but the overall gain is remarkable. WiFi networks can be carefully engineered to minimize interference and maximize throughput.

Beyond simply placing individual access points where they are most needed, clever engineers can utilize foliage and buildings in the surroundings to improve throughput.[34] These sorts of technological solutions are exactly the type of localized problem solving and bottom-up solutions are good examples of why we generally value market solutions over command and control. A diversity of independent actors can discover

Recommendations

First and foremost, policy makers should not take an overly-narrow focus on one particular efficiency (allocative efficiency) of one particular input (radio spectrum). Such a focus on auctions blinds us to the obvious and growing value of unlicensed services all around us. Services utilizing unlicensed spectrum are valuable contributors to the economy and should not get short shrift based on misunderstood doctrine.

It is common to think of unlicensed as a gap-filler, as an efficient way to fill guard bands with low-power devices that are unlikely to cause interference to licensed services. While this can be a great opportunity to maximize the use of spectrum, offering up only narrow slices of spectrum is not what unlicensed services deserve. Policy makers should consider new, dedicated unlicensed bands where possible.

The potential for economic growth through new unlicensed platforms, services, and devices is greatest when it has large, contiguous blocks of harmonized spectrum with simple service rules. Wherever possible, we should avoid creating specialized rules to protect particular incumbents from interference, allowing for simpler, cheaper equipment. All and all, this offers the best potential to maximize spectrum use, which is what professor Coase was really after.

ENDNOTES

1. Ronald Coase, "The Federal Communications Commission," The J. of L. and Econ., Oct. 1959 2 ("Coase, FCC"), *citing* S. Rep. No. 659, 61st Cong., 2d Sess. 4 (1910).
2. This was the business model of choice for Guglielmo Marconi, who is credited with the invention of the radio telegraph system in the late 1800s.
3. No doubt, there were problems with interference at the time, but the difficulties the radio operators had in communicating that the Titanic was sinking was due to other problems. At the time, ship's radio systems were designed to communicate passengers' letters – not for distress beaconing. Also, this was even before the now-famous telegraph distress signal "SOS" had been standardized. *See* Steve Cherry interview with Alex Magoun, "The *Titanic* Launched a Century of Emergency Response Technologies," IEEE Spectrum, Apr. 2012, http://spectrum.ieee.org/podcast/telecom/wireless/the-ititanici-launched-a-century-of-emergency-response-technologies.
4. The Radio Act of 1912, which was passed after the *Titanic* disaster, was the first attempt to regulate radio. The then U.S. Department of Commerce and Labor assigned and enforced licenses. A federal court found that the Secretary of Commerce lacked the legal basis to restrict radio operators. After a brief period of a "breakdown in the law" where interference was widespread, Congress
5. Barry Keating, "Economic dimensions of telecommunications access," International Journal of Social Economics, Oct. 2012, 885.
6. These pre-1965 broadcast hearings considered the following factors: "(1) local residency of the owners, who are expected to be thoroughly conversant with local needs, (2) integration of ownership and management, whereby the owners will take an active part in the day-to-day operation of the station, (3) active participation by applicants in civic affairs, (4) broad diversification of background and interests, and (5) past broadcast experience." *See* KPMG, "History of the Broadcast License Application Process," Nov. 2000, http://transition.fcc.gov/opportunity/meb_study/broadcast_lic_study_pt1.pdf.
7. *See* Coase, FCC *supra* note 1.
8. For Coase's comments on why he believes it took so long for his ideas to be accepted, *see* Ronald H. Coase, "Comment on Thomas W. Hazlett: Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years?," 41 Journal of Law & Economics, 577, 1998.
9. *See* Peter C. Cramton, "The FCC Spectrum Auctions: An Early Assessment," Journal of Economics and Management Strategy, 1997 for a discussion of these early auctions and their success.
10. For an excellent overview of unlicensed – its history, devices, and regulation, *see* FCC, Kenneth Carter, Ahmed Lahjouji, Neal McNeil, "Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues," OSP Working Paper Series, May 2003, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-234741A1.pdf.
11. Telecom Advisory Services, LLC, "Assessment of the Economic Value of Unlicensed Spectrum in the United States" Feb. 2014.
12. FCC Spectrum Policy Task Force, *Report*, ET Docket No. 02-135, Nov. 2002 ("SPTF Report") http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf. For an excellent discussion of the report itself, *see* John S. Leibovitz, "The Great Spectrum Debate: A Commentary on the FCC Spectrum Policy Task Force's Report on Spectrum Rights and Responsibilities, Yale Journal of Law & Technology, 2003-04.
13. SPTF Report Section VII, Spectrum Usage Models, 35-54.
14. Fred R. Shapiro & Michelle Pearse, "The Most-Cited Law Review Articles of All Time," 110 *Michigan Law Review* 1483 (June, 2012) http://www.michiganlawreview.org/assets/pdfs/110/8/Shapiro_and_Pearse_2013.pdf.
15. *See, e.g.* Thomas W. Hazlett & Even T. Leo, "The Case for Liberal Spectrum Licenses: A Technical and Economic Perspective" *George Mason University* 10-19, http://www.law.gmu.edu/assets/files/publications/working_papers/1019CaseforLiberalSpectrumLicenses20100412.pdf; Thomas W. Hazlett, David Porter, & Vernon Smith, "Radio Spectrum and the Disruptive Clarity of Ronald Coase" *George Mason Univeristy* 10-18; Thomas W. Hazlett, "Optimal Abolition of FCC Spectrum Allocation," 22 *Journal of Economic Perspectives* 103 (2008) http://arlingtoneconomics.com/studies/optimal-abolition-of-fcc-spectrum-allocation.pdf.

16 . For Hazlett's arguments as to the definition of rights, and against unlicensed, *see* Thomas W. Hazlett and Sarah Oh, *Exactitude in Defining Rights: Radio Spectrum and the "Harmful Interference" Conundrum*, George Mason University Law and Economics Research Paper Series, 12-55.

17. This point is key. Although Coase gained a reputation of a free-market thinker, his views were essentially pragmatic, comfortable with government intervention where necessary. Many have pointed this out before: *See,* e.g. Daniel A. Farber, "Parody Lost/Pragmatism Regained: The Ironic History of the Coase Theorem," 83 Va. L. Rev. 397 (1997); Robert H. Frank "Ronald Coase, a Pragmatic Voice for Government's Role," The New York Times, Sept. 14, 2013, http://www.nytimes.com/2013/09/15/business/ronald-coase-a-pragmatic-voice-for-governments-role.html.

18. Coase, The FCC *supra* note 1 at 29

19 . With this work, Coase was largely responding to English economist Arthur C. Pigou who is recognized with formalizing the concept of externalities.

20 . Coase, along with two other economists, William Meckling and Jora Minasian, wrote an in-depth report on spectrum policy reform with RAND corporation. Reportedly written in 1962, the paper was not formally published until 1995. Roanld Coase, William Meckling, & Jora Minasian, "Problems of Radio Frequency Allocation, RAND (1995) ("RAND study").

21 . For an excellent discussion of the misunderstandings of Coase's work, *see* Deirdre McCloskey, *Other Things Equal: The So-Called Coase Theorem*, 24 Eastern Economic Journal, 367 (1998), *available at* http://www.deirdremccloskey.com/docs/pdf/Article_306.pdf.

22 . For a stimulating debate over how far we should go in defining spectrum rights, *see*, Philip J. Weiser & Dale N. Hatfield, "Property Rights in Spectrum: A Reply to Hazlett," 15 Geo.Mason L. Rev 1025, *available at* http://demotesturl.com/george-mason/wp-content/uploads/2014/03/15-4_Weiser.pdf.

23 . Coase, The FCC *supra* note 1 at 27.

24 . The term "highest and best use," is somewhat circular in this context. Highest and best use, borrowed from real estate, is the most valuable *legal* use of a property. Even "flexible use" assumes technical rules that constrain the possible legal uses.

25 . It is arguable whether it's appropriate to refer to spectrum as a "natural resource." As Milton Mueller writing for the Cato Institute puts it, "This characterization of the electromagnetic spectrum is fallacious and misleading. The spectrum is not a 'natural resource'; it does not even exist independently of specific transmitters and receivers. The economist's and politician's treatment of the spectrum as a resource is strangely reminiscent of the 19th-century belief in the existence of an "ether" -- an invisible, incorporeal medium through which radio waves pass." Milton Mueller, *Property Rights in Radio Communication: The Key to the Reform of Telecommunications Regulation*, Cato Policy Analysis No. 11, http://www.cato.org/pubs/pas/pa011.html.

26 . Robert Matheson and Adele Morris have laid out an excellent explanation of these dimensions in arguing for more granular definition of spectrum rights. *See* Robert Matheson & Adele C. Morris, *The Technical Basis for Spectrum Rights: Policies to Enhance Market Efficiency*, Brookings (Mar. 3, 2011), http://www.brookings.edu/~/media/research/files/papers/2011/3/03%20spectrum%20rights%20matheson%20morris/0303_spectrum_rights_matheson_morris.

27 . Perhaps in the future software defined radios will come down in cost to the point where systems are more flexible in hopping from band to band, which may well justify a rethinking of spectrum policy. But for now that cost curve has a long way to bend and policymakers should assume radios are more or less purpose-built.

28 . *See, e.g.* William Lehr, "The Economic Case for Dedicated Unlicensed Spectrum Below 3 GHz," MIT (May 2004), at 39.

29 . Coase, The FCC, *supra* note 1 at 34.

30 . For the opposite argument, *see*, Jerry Brito, "The Spectrum Commons in Theory and Practice," 2007 Stan. Tech. L. Rev. 1.

31 . Raul Katz, "Assessment of the Economic Value of Unlicensed spectrum in the United States (Feb 2014), *available at* http://www.wififorward.org/wp-content/uploads/2014/01/Value-of-Unlicensed-Spectrum-to-the-US-Economy-Full-Report.pdf.

32 . For an excellent account of how WiFi contention management technology, combined with standards bodies have allowed for commercial deployments utilizing unlicensed spectrum, *see* David P. Reed & Jim

Lansford, "Wi-Fi as a Commercial Service: New Technology and Policy Implications," TPRC 41 (Mar. 2013), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2238158.

33 . *See* Rob Alderfer, "Wi-Fi Spectrum: Exhaust Looms," CableLabs (May 2013), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2411645; For the opposite side of this debate, *see* Pierre de Vries *et al.*, "The Emperor has No Problem: Is Wi-Fi Spectrum Really Congested?" (Oct. 2013) *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2241609. The author believes this debate is largely ancillary to the case for more unlicensed spectrum - additional unlicensed is justified regardless of whether we are currently at capacity.

34 . *See, e.g.,* Rory Conaway, Tales From the Towers, Ch. 13 Interference Is Not Just a Hockey Penalty (Sept. 2010), http://www.triadwireless.net/tales-from-the-towers/comments/Chapter-13--Interference-Is-Not-Just-a-Hockey-Penalty.

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