A Framework for Determining the Optimal Mix of Spectrum Management Regimes*

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Abstract

This paper pursues three goals. It first discusses why a mix of exclusive rights and open access regimes is the norm in many areas of resource allocation. Arguing that such coexistence can also be expected in spectrum, the paper identifies the determinants of the optimal mix of spectrum management regimes. Second, the paper discusses and illustrates ways of measuring the opportunity costs of spectrum for licensed and unlicensed uses. We suggest that the curvature of spectrum value curve can be used as a tool to assess the flexibility of spectrum management regimes. Third, seeing the optimal mix of spectrum in a dynamic manner, we provide a few thoughts on adaptive spectrum management regimes. Regulatory authorities would be well-advised to increase the use of methods to systematically evaluate the economic value of spectrum for unlicensed and licensed use, Moreover, it is useful to boost spectrum liberalization policies to enhance efficiency in spectrum use.

Key words: Spectrum; Determinants; Optimal mix; Efficient use

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1 Introduction

All resources on earth, as Locke mentioned in the 17th century, were once available in common to everybody who was willing to and able to use them.[1] In other words, they were initially organized as open access resources. History reveals that many resources gradually were reorganized as private property even though a substantial portion (e.g., air, fish in the high seas, and land in public domain) continues to be an open access resource. A stark example that underwent such a transition is land. The driving forces that turn open access resources into private properties are well recognized in the research literature. According to Gordon (1954) and Demsetz (1967), demand increase caused by population growth and international trade is a major factor that converted abundant open access resources into scarce ones and then turned them into common or private properties. Stevenson (1991) pointed out that new technologies that create new services also increase demand for resources, as happened in wireless telecommunications. Through human history, demand increase caused by population growth, new technologies, and economic growth have led to adjustments in the governance regimes of many resources which were once available freely to the public into private properties. As the scarcity of resources has increased, privatization of open access resources also has deepened.

Spectrum has and most likely will continue to follow the same wave of transition that other resources passed through long time ago. Spectrum is legally considered public

[1] Adapted from Epstein (1994, p. 17).

property in most countries but the government has granted rights for both exclusive and shared uses. For the sake of clarity, we adopt the following convention in this paper. Exclusive ownership, non-exclusive open access, and other forms of spectrum management regimes, are characterized by specific bundles of property rights along a spectrum of dimensions, including access, use, alienation, and management of a resource (see Ting, Bauer, and Wildman, 2003). These rights may be unrestricted or constrained. For example, ownership may be exclusive and unlimited or it may be curtailed in certain areas. In and the U.S., first forms of common use were introduced 1938.[2] As Epstein (1994) mentioned, the coexistence of private and common property has been the norm throughout human history and a situation in which one system completely dominates the other has been the exception. This has also been true for the utilization of the spectrum resource.

It can be said that open access to a resource is unstable and can be undesirable in the sense of economic welfare not because of its intrinsic nature but because of changing market environments caused by demand increase and new technology. We think that this pattern is also true of spectrum. In short, as Epstein (1994, p. 23) said, “[N]o single regime of property rights will be good for all times and for all occasions.”

Nowadays, a growing number of contributions to the literatures seem to emphasize increased reliance on market forces in searching for a mix of the two competing approaches of spectrum management and even in choosing the technical specifications of commons.[3] However, it is also easy to find papers arguing that the market approach has substantial

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[2] The first unlicensed device was authorized by the FCC in 1938 (Carter et al. 2003).

[3] See Baumol and Robyn (2006), Cave (2006), Hazlett (2006a, b), OECD (2005), Brennan (1998), De Vany (1998), Hazlett (1998) for this line of reasoning. In particular, Benjamin (2007) points out that a private commons competing with other commons is more receptive to new technological standards like protocols and more efficient than direct government control or public commons.

limitations and emphasizing the needs for government intervention in spectrum management. For example, Leibovitz (2003-2004) argues that the current spectrum management policy, manifested in the report of the Federal Communications Commission (FCC) Spectrum Policy Task Force in 2002, is slanted toward the property rights approach and against the open access model.[4] Observing and participating in the debates on future spectrum management policy, the FCC has experimented since the 1990s with regimes that resemble more property right and others that resemble open access regimes.

Observing these recent trends and developments in the research on spectrum management policy, this paper pursues three goals: It first discusses why a mix of the two regimes is the norm and identifies the determinants of the optimal mix of spectrum management regimes. Second, the paper discusses and illustrates the ways of measuring opportunity costs of spectrum for licensed and unlicensed uses and suggests that the curvature of spectrum value curve can be used as a tool to assess the flexibility of spectrum management regimes. Third, seeing the optimal mix of spectrum in a dynamic manner, we provide a few thoughts on adaptive spectrum management regimes.

The next section reviews briefly recent developments in the debates on spectrum management policy. Section 3 presents a framework (model) with which we can explain the optimal mix of spectrum management regimes and identifies determinants of the optimal mix. Section 4 discusses and illustrates the ways of measuring opportunity costs of spectrum for licensed and unlicensed uses. Section 5 closes the paper with providing a few thoughts on the flexible, adaptive institutional arrangements.

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[4] Benkler (2002) and Noam (1998) share the same views.

2 Recent developments in the spectrum management policy debate

As the “great spectrum debate” termed by Leibovitz (2003-2004) began cooling down recently, the focus of research efforts began shifting from abstract and ideological topics to more specific and practical ones such as the positive, constructive roles of regulator (government) in spectrum management (Goodman 2004; Baumol and Robyn 2006), adaptive and flexible spectrum management regime (Baumol and Robyn 2006; Hazlett and Bazelon 2007; Benjamin 2007; Faulhaber 2005; Werbach 2003-2004), interference dispute resolution process (Goodman 2004), and wholesale access licensing which is a hybrid of exclusive use right and open access approaches (Wilkie 2007).

The prolonged debates on spectrum management paradigms, in particular on the relative merits of property right regime versus open access (commons) regimes, seem to be converging to the conclusion that a priori we do not know which approach is better than the other and one cannot eliminate the other.[5] Recent research by Baumol and Robyn (2006), Lueck and Miceli (2006), Cave (2006), Faulhaber (2005), Goodman (2004), Werbach(2003-2004), and reports by the OECD (2005), confirm that the “spectrum version” of an old adage—one spectrum management regime does not fit all situations—is right, at least considering current technological and economic environments of wireless communications industry. Lueck and Miceli (2006) point out that in other areas, such as land use, a mix of property right regimes exist, visible along several dimensions such as ownership or access to the resource. For example, land is owned by the state as well as individuals. Likewise, in the access dimension, open, shared and exclusive access coexist without regard to the

[5] There are still scholars like Hazlett (2006a, b) who strongly support complete privatization of spectrum. Hazlett and Bazelon (2007) indicate that the FCC’s spectrum allocation for unlicensed use is simply an example of traditional command and control approach that the government regulates access to spectrum.

ownership style. Cave (2006) also supports this view: "it is unlikely that there will be a corner solution, with the same regime optimal in all frequencies." Goodman (2004) similarly indicates that spectrum with both characteristics of land and air will be managed by private property rights and commons approaches in the future.

It is not difficult to see that even advocates of commons regime acknowledge explicitly or implicitly that various mixes of property rights systems exist in real world. Actually, what commons advocates worry about is complete privatization of spectrum resources, which indirectly means that they prefer a mix of property right regime and commons regime to a pure property rights system.[6] Buck (2002), advocating commons regime, points out that a lot of property rights system mixing private property and commons exist in the real world in an attempt to rebut the pervasive use of spectrum auctions.

In sum, it is a valid proposition that a mix of the two regimes will be the norm in future spectrum use and ownership structure as we can nowadays observe the same phenomenon in land use and ownership. Then, a natural conclusion we can make based on the proposition is that it is time to turn our attention and energy to the questions of "why a mixed [regime] should dominate either of the two extremes (Epstein 1994, p.20)," what determines the optimal mix, how the mix changes, and how we can facilitate the evolution of the mix toward optimum.

3 Optimal mix of spectrum management regimes

3.1 Access to spectrum

[6] Benkler (2002) and Noam (1998) argue that the government should increase spectrum for commons or open access and experiment, wait, and see which regime is better for the economic wellbeing of society. Werbach (2003-2004) suggests a universal open access approach to which private property rights system is tacked.

The purpose of this section is to identify determinants of the optimal mix of private property and commons (open access) regimes by drawing on microeconomics theory as stated in the introduction. Before doing so, one thing made clear is to make an operational definition of property rights because, as is well known, property rights are composed of many "distinctive rights" (Robinson 1998). Ownership of spectrum channels is still denied officially in the United States (47 U.S.C. § 301) and in many countries, but firms with spectrum license enjoy various features of de facto property rights—exclusivity, transferability, and ability to subdivide and lease spectrum channels within constraints set by regulatory authority. In addition, the high likelihood that an exclusively assigned license will be renewed provides quasi-ownership for wireless communication firms. Therefore, this paper views firms with spectrum license for exclusive use as ones that enjoy privileges that are in many ways similar to private property control over the spectrum assigned to them, and this allows us to analyze the mix of two regimes.

Then, which spectrum bands can be classified as belonging to property rights regime? , This paper focuses on exclusive use of spectrum in classifying spectrum bands belonging to property rights regime because it is not only a major feature of property rights but also an opposite concept of commons (open) access. Therefore, mixing property right regime and commons regime in this paper means mixing exclusive use and commons use. A little bit differently speaking, the feature of exclusive use of spectrum is used as a proxy for a property right regime. Because this paper focuses on the optimal mix of access regimes governing spectrum use, the command and control regime, which has traditionally been considered as one of tripartite spectrum management regimes, is ignored in this paper. This is because the major concern of this paper is not who owns and controls spectrum but how it is used.

Current spectrum management system is quite similar to the land management system of China where private land ownership is not allowed but individuals and firms can use land for residence or business within the constraints set by the government (Zhang and Pearlman 2004). China's vigorous economic growth for past two decades testifies that private ownership of an important economic resource may not be a necessary condition for the effective use of that resource as long as other features of private property rights like transferability, divisibility, changeability in use, and so on are allowed (Zhang and Pearlman 2004).[7] In other words, ownership dimension of a resource can be separable from access dimension without reducing economic efficiency significantly in the use of that resource, which means that whether private ownership is better than public ownership in facilitating efficient use of a resource is another problem separable from the problem of how to use it.

3.2 Evolution of the mix of two regimes and its current status

It was not until Heinrich Hertz demonstrated wireless communication technology in 1888 that spectrum began to be recognized as a useful resource (Aitken 1994). After the invention of wireless communications technology, spectrum was initially abundant open access resource, but it began to be considered as a scarce economic resource with the advent of the radio broadcasting industry, the first commercial use of spectrum on a large scale (Minasian 1969). Spectrum had been an open access resource both in ownership and access dimensions in the United States until the enactment of the Radio Act of 1927 that precluded the ownership of spectrum and any further rights beyond those specified in each

[7] Foreign Policy (2007) also points out the fact that Chinese economy has grown six times for two decades after 1984 even though lacking solid private property rights protection.

license and adopted a licensing system for spectrum use.[8] In other words, any users could contend to use spectrum channels before the enactment of the Radio Act of 1927. After the Act was enacted, in ownership dimension the public ownership of spectrum was consolidated by statute, whereas in access dimension channels of spectrum were assigned to users for exclusive uses.

Considering that the Radio Act of 1927 was a watershed that changed spectrum from an open access resource to an exclusive access resource, it can be said that open access to spectrum was the norm until 1927 in the United States. After 1927, exclusive use had been a norm until unlicensed use of spectrum began from 1938 even though, in the years inbetween, commons use had not been completely obliterated.[9] In other words, focusing on the access dimension of spectrum usage rights, it can be said that two regimes of spectrum management have coexisted since 1938 in the United States.

In the United States, as of 2006, 753 MHz of spectrum below 3 GHz is allocated for exclusive licensed use and 129.5 MHz is allocated for unlicensed use (Snider 2006). Snider (2006) argues that current unbalanced allocation of spectrum between licensed and unlicensed uses should be redressed without specifying the criterion that would govern the reallocation.

3.3 Why is a mix of two regimes the expected outcome?

Most scholars and researchers agree that two regimes of spectrum management will coexist in the future even though there are still a few arguing that either one of the two regime is not needed. Those who support the coexistence of the two regimes claim that the

[8] Aitken (1994, p. 689) stated that “The right to deny access to the spectrum first appeared in the Radio Act of 1927 …. ” Even though spectrum licensing system was introduced by the 1912 Act to Regulate Radio Communication (Goodman, p. 280), it was “merely a matter of registration (Aitken (1994, p. 688).”

[9] Amateur radio communications, a form of open access (shared use), were allowed even after 1927.

spectrum management system should be flexible to accommodate new technologies and market uncertainties. Baumol and Robyn (2006) basically prefer property right regime and emphasize that regulatory authorities should implement a spectrum management policy which does not create any vested interests because they might block future evolution of spectrum use following changing environments. Werbach (2003-2004) also points out the importance of flexibility in spectrum management even though he believes that a property rights regime is more rigid than a universal open access regime (what he calls supercommons) in adopting new technologies. Noam (1998) and Benkler (2003) seem to foresee the convergence toward open access regime even though at present they agree on mixing both regimes. In short, even those who can see the virtues in other approaches still often strongly prefer one of two regimes.

To the best of our knowledge, so far no literature has dealt with why a mix of two regimes, commons and private property, should or would be a norm. Epstein (1994) is the only exception, but it is not about spectrum but resources in general. Because spectrum is an economic resource, Epstein's basic ideas can also be applied to spectrum. Epstein (1994) focuses on the fact that the two systems have different strengths and weaknesses. One's strengths are the other's weaknesses, and vise versa. According to Epstein (1994), commons, open to everyone, entail coordination costs and may weaken "the incentives for production and trade."[10] Private property system, closed to everyone except the owner, brings forth exclusion costs, which means the utilities of those excluded from use, but it generates positive externalities like fostering trade and business. Epstein sees the tradeoff between the two systems as a reason for the dominance of mixed regime over either extreme pure

[10] One example of coordination problem is who is going to use a better quality band.

system. He argues that the optimal mix, balancing costs of coordination and exclusion, will be attained at a point that maximizes economic value from resource.

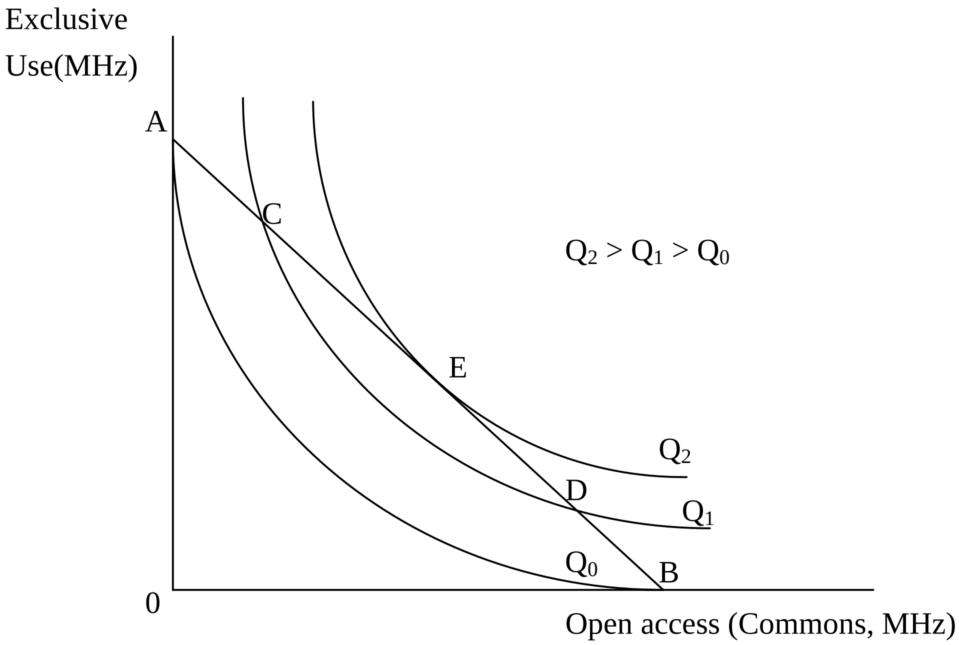

Figure 1: Convexity in production of wireless services

When Epstein's intuition is applied to spectrum use, it can be said that a mix of two regimes, rather than a pure one, is a norm in spectrum use. Put this using an economics jargon, there should be at least a factor that results in convex production function of wireless services. Convexity in production of wireless services means that a linear combination of two regimes generates higher efficiency in producing the same combinations of wireless services, Q, than either one of them does.

This concept is illustrated in Figure 1, where x-axis measures the amount of spectrum allocated for open access (unlicensed use) and y-axis measures that allocated for exclusive use (licensed use). A and B, producing Q_0 level of outputs, represent the extreme choice of two regimes, i.e., a society chooses exclusive use or open access. However, a mix of the two regimes generates greater production of a mix of services as presented by C and D, matched with Q_1 level of production.

In microeconomics, the convex preference in consumption stems from the law of diminishing marginal utility and the convex isoquant is caused by the law of diminishing returns. Then, what brings forth convexity in spectrum use? One possible explanation for convexity in production of wireless services comes from heterogeneity of communications services in spectrum use. Different services can be better accommodated by different spectrum access regimes. For example, some telecommunications services for financial transactions, health care, business transactions, and multimedia streaming services are likely to require higher level of service quality than others for emailing, chatting, and blog accessing. Telecommunications firms with exclusive property rights can guarantee a certain level of quality and meet consumer needs more flexibly at a lower cost than those without them because they are better positioned to control traffic and interference than those providing services on shared spectrum channels.

The statement that different services can be better accommodated by different spectrum access regimes means that a sort of law of diminishing returns is working in the production of wireless services. Coordinate A exemplifies a case where all service providers using spectrum are required to obtain license for exclusive use of a spectrum band. In other words, even auto manufacturers need to purchase a certain band of spectrum to sell keyless door operators and tire pressure monitoring system, which are functions currently provided through unlicensed bands. Requiring that all services that were provided on unlicensed bands shall be provided through separate exclusive use spectrum bands will most likely create great inefficiencies (underutilization or overutilization) in spectrum use.[11] Under this situation, if a band of spectrum is opened for unlicensed use, the efficiency in spectrum use will initially increase greatly. However, as more bands are added to unlicensed use, the efficiency gain will diminish.

In short, it can be said that, as long as there exists heterogeneity of wireless communications services in terms of spectrum use, interior solution dominates corner solution in spectrum use.

3.4 The optimal mix and its determinants

In terms of society, the optimal mix of two different spectrum management regimes can be defined as a combination that maximizes social welfare as measured by consumer and producer surplus generated by the wireless communications industry. We can find the optimal mix of two regimes by drawing on standard microeconomic theory. If a relative price (measured by opportunity costs of spectrum at the margin) of spectrum used for exclusive use and open access is the slope of a downward sloping straight line in Figure 1, the optimal mix of two spectrum regimes occurs at E, provided that spectrum usage constraints, at present imposed by regulators, are liberalized and spectrum trading is allowed. If spectrum is perfectly divisible and interchangeable between licensed and unlicensed uses, a society (or a competitive market) chooses a mix that equalizes marginal net benefits from both uses of spectrum. E in Figure 1 illustrates this outcome.

Put what is mentioned above a little bit more rigorously, at the margin the economic values of spectrum from both uses should be the same as shown Equation (1). The value of

[11] Wireless Internet service is provided through the ISM (Industrial, Scientific, and Medical) band. If the band is used for only industrial, scientific, and medical equipments, it would be underutilized than it is now.

marginal product (VMP) from the last unit of licensed spectrum (S_L) is equal to the price (P_L) of the licensed communications service times the marginal product (MP) of the last unit of spectrum for that service.[12] The same rule applies to the VMP(S_U) from the last unit of unlicensed spectrum (S_U), the right hand side of Equation (1), where P_U is the price of unlicensed communications service.[13]

$$P_{\mathrm{L}} \times MP(S_{\mathrm{L}}^{*}) = \mathrm{VMP}(S_{\mathrm{L}}^{*}) = \mathrm{VMP}(S_{\mathrm{U}}^{*}) = P_{\mathrm{U}} \times MP(S_{\mathrm{U}}^{*}) \tag{1}$$

The optimal mix of the two regimes, illustrated by E in Figure 1, is the ratio of $S_{\mathrm{L}}^{*} / S_{\mathrm{U}}^{*}$. Equation (1) also applies to a monopolistic spectrum market, i.e., at the margin VMP(S_{L}^{*}) should be the same as VMP(S_{U}^{*}) for efficient use of spectrum.[14] Essentially, the problem of efficient use of spectrum is the same as that of allocating an input for two different uses (industries).

Then, what determines the optimal mix? From Equation (1), we can easily figure out the determinants of the optimal mix. Since the optimal mix is the ratio of the spectrum demanded for licensed use and that for unlicensed use at equilibrium in spectrum market (or in society), its determinants are the determinants of demand for both uses of spectrum.[15] Next two subsections discuss the determinants of demand for both licensed and unlicensed

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[12] The price of licensed service is being used to refer either to a price set in a market for the service, or an implicit price calculation based on a welfare function.

[13] The price of unlicensed service P_U, except for wireless Internet service, does not exist because users of unlicensed devices do not pay for the service. However, they have to purchase unlicensed devices, so P_U can be thought of as a fee for a service or a price for an unlicensed device.

[14] If market is not competitive, VMP becomes marginal revenue product (MRP), which is marginal revenue multiplied by marginal product from the last unit of spectrum.

[15] In a society where spectrum market is not existing or functioning, government will determine the mix of spectrum for two different uses. It would not be an invalid proposition that in the long run government choices of the mix would converge to market equilibrium that could be attained if market had exited because government would pursue efficient use of spectrum by somehow evaluating implicit values of marginal product from the two different spectrum uses.

spectrum uses, which are eventually determinants of the optimal mix.

3.5 Determinants of demand for spectrum

Equation (1) shows that demand for S_L and S_U depends on P_L, P_U, and marginal products of spectrum for both uses. P_L and P_U depend on the determinants of demand for and supply of services using spectrum. Therefore, the determinants of prices for wireless services are those of demand for S_L and S_U. Put differently, demand for spectrum is a derived demand from the demand for services using spectrum because spectrum is not a final product or service that consumers consume but an input used for production of wireless communications services. As shown in Equation (1), marginal products of spectrum also affect demand for spectrum, but their effects are taken into account by the supply side determinants of P_L and P_U, and do not need to be dealt with separately. The determinants of price of a good or a service are well recognized in standard microeconomics textbooks, and Equation (2) shows the functional relationship between demand for spectrum S and its determinants.

$$\begin{aligned} S &= f(Q_L, Q_U) \\ &= g(\mathbf{p}, \mathbf{p_o}, I, Pop, T\mathrm{a}, T\mathrm{e}, \mathbf{w}, E, O) \end{aligned} \tag{2}$$

where Q_L and Q_U are equilibrium quantities of wireless services demanded using licensed and unlicensed spectrum, $\mathbf{p}$ is prices of wireless communication services using license and unlicensed spectrum, $\mathbf{p_o}$ is prices of complements and substitutes, I is household income, Pop is population, Ta is taste, T_e is technology, $\mathbf{w}$ is prices of inputs including that of spectrum, E is expectation on future demand and supply, and O is other factors.

Demand for wireless services, ceteris paribus, increases with income and population and demand for spectrum does as well. If the same service is provided through both licensed and unlicensed spectrum, an increase in demand for wireless services caused by higher income and greater population will increase demand for both types of spectrum. Therefore, in such a case, we do not know exactly whether they will eventually increase the optimal mix of spectrum or not. However, we can make assumptions, notwithstanding, about the effects of demand side determinants on the optimal mix. If licensed use of spectrum leads to better quality services than unlicensed use, then we are likely to observe a greater share of licensed use of spectrum as income grows. Changes in prices of complements and substitutes also alter demand for spectrum of both uses by affecting the demand for the wireless services. For example, in countries where wired communications services, substitutes of wireless services, are well developed, the demand for spectrum will be relatively low. Consumer taste also affects the optimal mix. In countries where demand for real-time, secured, and guaranteed quality of service is high, a greater share of spectrum is likely to be used for licensed use.

From supply side, the effect of technologies improving efficiency in spectrum use on the optimal mix is unclear. A spectrum saving technology might enable licensed spectrum users to release some spectrum for unlicensed use, or conversely government can transfer some unlicensed spectrum, which becomes idle because of increased efficiency in spectrum use, to licensed one. If dynamic spectrum sharing technology turns out to be robust and secure enough to be used for services currently provided through licensed bands, as supporters of open access foresee, the share of licensed use will shrink drastically. Technologies expanding usable spectrum to higher frequency band for wireless communications will also affect the optimal mix even though a priori their effects on it are unclear. Changes in other factor prices also alter demand for spectrum. Since spectrum is not the only input used for the production of wireless communications services, the changes in other factor prices alter the input mix of spectrum with other inputs and eventually alter marginal product of spectrum too. For example, if prices of handsets or unlicensed devices fall, the demand for spectrum rises. Expectation on future demand and supply of wireless services affects demand for spectrum and, in turn, the optimal mix.

Other factors, which alter demand for wireless services and eventually the optimal mix, include government regulation policy on spectrum use, other communication technologies other than spectrum technologies, and location of country. Government regulation policy on spectrum use is obviously an exogenous factor that affects the optimal mix because the spectrum quantity allocated for unlicensed use is still determined by government even though it does its best to ease excess demand for spectrum for various uses in wireless communications industry. Other communication technologies also affect the optimal mix. One example is the next generation converged network (NGcN) and one of whose features that distinguish it from current network is its ability to provide differentiated quality of services (Kwon and Nam 2004). If core network evolves fully to the stage that the NGcN technologists envision, wireless part of the service delivery channels should be able to accommodate such feature. This is likely to result in an increase in the share of licensed use of spectrum because proprietary network is easier to accommodate such a capability. Exclusive use of spectrum is likely to provide more predictable and stable business environment for firms by lowering interference possibility than shared use of spectrum, and in turn it can facilitate investment in nationwide communications network. If this presumption is valid, it can be said that technology that reduces sunk costs in wireless communications industry is likely to lower the share of licensed use of spectrum.

Locational characteristic of a country, i.e., whether it is isolated or not from other countries, is also an important factor that affects the optimal mix because of interference problem in wireless communications. Isolated countries due to sea or mountains use more spectrum freely than others, and their spectrum abundance can substitute for complex and expensive spectrum sharing technologies.

3.6 A caveat to applying microeconomic theory to unlicensed spectrum

The previous subsection on determinants of the optimal mix of two spectrum management regimes is mainly based on standard microeconomic theory, which works well in free market where private property rights are protected. Such adaptation of microeconomic theory to licensed use of spectrum is reasonable, but applying it to unlicensed use spectrum can be problematic because no one but government owns it.

Traditionally, when congestion occurs in unlicensed bands, unlicensed device manufacturers or users filed complaints to government, and then government, after evaluating congestion levels, allocated extra spectrum, if necessary, for specific unlicensed uses. In other words, government has allocated unlicensed spectrum instead of markets simply because markets for unlicensed spectrum cannot exist under current spectrum regulation frameworks. Even though private commons can exist in some niche markets, it seems that it cannot replace the whole unlicensed bands. This means that government would or should play the role of allocating spectrum for unlicensed use and the role of rule maker for shared uses like underlay and overlay uses of spectrum even in the future. Therefore, it can be argued that the discussion of the previous subsection on the optimal mix of the two regimes is not applicable to unlicensed use spectrum.

However, government has to compare economic value from unlicensed use of spectrum with that from licensed use of spectrum at the margin in order to use limited spectrum efficiently. [16] This means that it has to develop ways to estimate economic value of unlicensed bands notwithstanding the practical difficulties in estimating economic values of unlicensed spectrum. Therefore, the discussion of the previous subsection can be considered useful even though we are currently facing formidable difficulties in utilizing the ideas of the subsection for empirical analysis.

4 Estimating the opportunity costs of spectrum management regimes

Theoretically, the optimal mix of two spectrum management regimes, which is the mix that equalizes values of marginal products from the last units of spectrum for both uses, can be found from Equation (1). If spectrum market is competitive and well functioning, the competitive market equilibrium is efficient by the first theorem of welfare economics. However, in reality, a spectrum market does not exist and government still allocates spectrum for unlicensed uses in most countries. Therefore, in order to help government figure out the optimal mix of two regimes, it is necessary to find a practical way to estimate values of marginal product of spectrum.

If demand for spectrum is competitive and spectrum is the only fixed factor in wireless communications industry, eventually spectrum absorbs the economic rents of the industry according to bid-rent theory. The maximum amount of bid for spectrum is the profit of wireless service business, which is the leftover remaining after opportunity costs of all inputs other than spectrum are compensated. The production function of a wireless service

[16] To estimate economic value of unlicensed spectrum, it would be necessary to estimate outputs of unlicensed device industry as well as consumers' willingness to pay for unlicensed device uses.

X is assumed to have three arguments, labor (*L*), capital (*K*), and spectrum (*S*) as shown in Equation (3). Total cost (*TC*) function becomes Equation (4) under the production function.

$$X = X(L, K, S) \tag{3}$$

$$TC = wL + rK + p_s S \tag{4}$$

where *w*, *r*, and p_s represent the prices of labor, capital, and spectrum per MHz respectively. If total revenue (*TR*) is used up for the compensation of inputs, *TC* is equal to *TR*. After replacing *TC* with *TR* and solving for p_s, we obtain Equation (5). Equation (5) can be generalized to Equation (6) because there are many production inputs utilized in wireless service production. In Equation (6), total cost other than spectrum is categorized into operating cost (*OC*) and cost of capital (*COC*).

$$p_s = (TR - wL - rK)/S \tag{5}$$

$$p_s = (TR - OC - COC)/S \tag{6}$$

Finally economic value of spectrum (*EVS*) is can be defined as net present value of profit defined as shown in Equation (7).

$$EVS = \sum_{i=1}^{n} \frac{p_s S}{(1+d)^i} = \sum_{i=1}^{n} \frac{(TR_i - OC_i - COC_i)}{(1+d)^i} \tag{7}$$

where *i* is license period (1 … n), and *d* is market discount rate.

Between 2001 and 2006, the Korean cell phone service industry had three wireless communications firms, mainly providing 2G or 2.5G wireless services, and recorded an annual profit of $1.7 billion on average. Under the assumptions that the average profit continues for 20 years, the maximum license period in Korea, and discount rate is 6%, *EVS* becomes $20 billion, which is the economic value of spectrum originally allocated for 2G mobile telephony services. Since 110 MHz spectrum is allocated to 2G mobile services, the economic value of spectrum allocated for 2G in Korea can be estimated roughly to $181 million/MHz.[17] Snider (2003) estimated economic value of spectrum using auction data and sales data of broadcasting industry. According to his estimation, economic value of spectrum for mobile communications is $1.19 billion per MHz and those for UHF and VHF TV service and radio service are $65.1 million and $2.3 billion respectively.

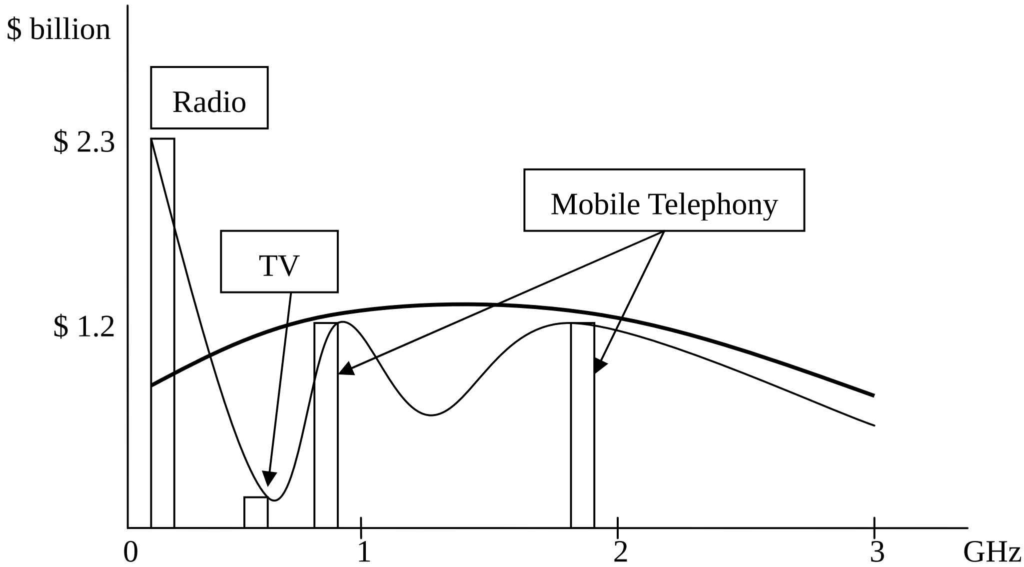

Figure 2: Economic value curve of spectrum

As long as government can estimate economic value of spectrum for a few specific bands, it can figure out opportunity cost of other spectrum bands by extrapolating or interpolating. Extrapolation and interpolation of estimated economic values spectrum result in an economic value curve of spectrum as shown in Figure 2. It is true that, as Snider (2003) pointed out, the estimated economic values of spectrum above can be seen as exaggerated because they are estimated under current regulation system. If spectrum use would be

[17] Snider (2003) calculated economic value of spectrum per MHz per person, where person is total population, potential customer base. Economic value of spectrum changes with demand, so economic value of spectrum per MHz (or that per MHz per user) represents more accurately than that used by him.

liberalized, the estimated values of spectrum could be lower than they were. However, one thing that identifiable clearly from the current wriggling economic value curve of spectrum in Figure 2 is that current use of spectrum is inefficient because, if spectrum use were efficient, adjacent spectrum bands should have had similar economic values as presented by the thick smoothly curved hypothetical economic value curve.

Therefore, government can roughly figure out the contour of economic value curve by estimating the economic value of spectrum for various uses. If economic values of unlicensed bands produce economic values that are similar to those of adjacent licensed bands, the mix of two regimes can be considered optimal. One critical problem facing this approach is the way to estimate economic values of unlicensed bands. Simply, we can estimate economic values of unlicensed bands using sales data of unlicensed devices if they are easily available.[18] However, these estimates could understate true economic values of unlicensed bands because consumers usually use unlicensed bands free once they purchase devices.[19] Therefore, estimation of economic values of unlicensed spectrum should be complemented by the estimation of consumers' willingness to pay.

5 Adaptive institutional arrangements

In their comparisons of property rights and commons regimes, many scholars have emphasized the importance of a flexible spectrum management system. Baumol and Robyn (2006) think a good spectrum management system is one that facilitates "easy adaptation to changing circumstance" and minimizes vested interests on spectrum. They advocate property rights approach complemented by flexible secondary market system. In contrast to

[18] As Carter et al. (2003) points out, obtaining sales data for unlicensed devices is often difficult because there are many small producers and many of them are foreign firms.

[19] One exception is wireless Internet service. Consumers usually have to subscribe service from wireless Internet service providers.

Baumol and Robyn’s view, Werbach (2003-2004) suggests a mix of regimes that have open access as major spectrum use method backed by private property and commons even though he acknowledges that commons can be less flexible than property rights system (p. 970). In short, scholars dream the same dream but their views differ in the ways to attain it.

An adaptive spectrum management system should be determined not by beliefs or abstract reasoning but by a practical index. Otherwise, the discussion on adaptive spectrum management system can hardly provide useful information to policy makers. Therefore, this section discusses how to judge whether one or a combination of spectrum management systems is more flexible than others and provides a few thoughts on adaptive spectrum management regimes.

5.1 A way to judge the flexibility of spectrum management regimes

A flexible spectrum management regime in normative perspective is an efficient one that maximizes social welfare from the spectrum available in a country. However, it is not easy to judge practically which regime results in efficient use of spectrum. If spectrum management system is flexible and spectrum is used efficiently, the value curve of spectrum over frequency domain should be smoothly curved rather than wriggling as shown in Figure 2. Then, a flexible spectrum management regime can be defined in positive perspective as one that generates a value curve of spectrum illustrated by the thick curve in Figure 2. Depending on the relative abundance of spectrum in a country, say spectrum bandwidth per person, the location and shape of the value curve could vary country by country and over time as well. Even though it is not easy to estimate the economic value of spectrum, we can trace the changes in the value curve of spectrum over time and cross countries as long as we use consistently the same method of estimation. By doing so, we can figure out which mix of spectrum management regimes brings forth a more continuous and smooth value curve of spectrum.

5.2 A few thoughts on adaptive spectrum management regimes

Advocates of property rights regime view that free market system backed by full property rights is the most flexible and adaptive spectrum management system.[20] As we can see from the land use in China, however, government can enable those who have only spectrum use rights without ownership to enjoy the capabilities that owners can exercise. As discussed early, it may not be a necessary condition for efficient use spectrum to adopt a fee simple ownership system in spectrum management system because flexible spectrum use rights with high renewal expectation can function as well as fee simple full property rights do. Public (government) ownership has an advantage over private ownership because it can mitigate holdout problem and make it easy for government to reallocate and reassign spectrum whenever needed because of technology developments. No ownership for spectrum can do more good than harm especially when market uncertainty is high because of technology development by lowering the cost of solving holdout problem. Then, an imminent task in the reform of spectrum management regime can be said to be spectrum liberalization rather than spectrum privatization.

Many scholars point out the constructive role of government in spectrum management even under deregulated and liberalized spectrum management system, especially with regard to unlicensed use of spectrum. Werbach (2003-2004), who emphasized the need of open access regime, also acknowledged the necessity of "bounded commons," which means

[20] Full property rights mean that owners can keep, transfer, and sell their properties at their will, and determine the usage of their properties.

that exclusive allocation of spectrum for one unlicensed use or a group of unlicensed uses. The dominant view on allocation of unlicensed use of spectrum seems to be that private commons cannot replace altogether unlicensed bands. Taking this view leads to the point that government should come up with a more efficient spectrum allocation method for unlicensed uses. So far, government has reacted to the demands of market in allocating spectrum for unlicensed uses. In other words, government has accommodated passively the demands for spectrum whenever someone or a company came with new service idea utilizing spectrum. A band of spectrum is allocated for new unlicensed use if exclusive allocation is thought to be necessary for it, and no band is allocated if existing unlicensed bands can house it. The current spectrum allocation method for unlicensed use takes a long time in responding to market needs because usually government is reactive, not proactive, to them. Specifically, government needs to arbitrate the conflict between incumbents and new entrants if it tries to house new uses in existing unlicensed bands and this can elongate the time for spectrum allocation for new unlicensed use. Government should be more proactive in responding to the needs of unlicensed device industry and, as mentioned before, it should also check the economic value of unlicensed spectrum and compare it with that of licensed band in order to attain efficient use of spectrum. To sum up, government needs to review current spectrum allocation process for unlicensed and strengthen the function of evaluating economic value of spectrum for unlicensed and licensed use. This will eventually contribute to enhancing adaptability of spectrum management regimes.

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