The Privatization of Radio Frequency Spectrum: Benefits and Implementation

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Abstract

The use of radio frequency spectrum is currently heavily regulated. In this paper, the authors propose a system for the privatization of these rights. This system would define rights to radio frequency spectrum in terms of three variables: time, area and spectrum. This would not only lead to a more efficient utilization of this resource, but also create a tax base that could serve as a source of federal government revenues.

I. Introduction

Throughout the world there exist considerable differences in the economic systems developed to allocate resources. The process can be thought of as a continuum. At one extreme all economic decisions are made by PLANNING while at the other extreme all economic decisions are made by the MARKET. No country's economic system can be described as either a pure planned economy nor as a pure market economy, although some obviously fall closer to one extreme or the other. Even within a particular country which may be described as market-oriented, such as the United States, there exist considerable differences concerning the relative role of the market vis a vis planning in the allocation of resources.

Consider the case of land. The allocation of land is largely determined by the market. However, there is much more government planning involved with land use than one would find in a completely market-oriented economy. For example, in the United States a substantial amount of land is not privately owned but is in fact in the public domain, owned by federal, state, or local government. Even for the land which is private property there are considerable restrictions on its use. These include zoning laws, rent control, environmental regulations, and real estate taxation. However, despite all of these government intrusions the market still performs a major role in decisions concerning the allocation of land. Owners of land have inherent property rights, which are exercised freely within the constraints described above.

Contrast this with our treatment of radio frequency spectrum. Radio frequency spectrum is a resource which is allocated largely with government planning, with the market performing only a minor role. Users of radio frequency spectrum are given certain rights for the use of particular parts of the spectrum. These rights carry considerable restriction as to transmitter power, antenna height and gain, modulation technique, and even in the case of broadcasting, program content. The owners of such rights (licensees) are not free to use their rights except in very narrowly defined ways. They are not free to directly sell these rights, although this can sometimes be achieved indirectly such as by the sale of a broadcasting station which includes the license giving rights to the spectrum.

It is the thesis of this paper that there is nothing inherent in the technical, social, or political nature of radio frequency spectrum which precludes the establishment of private property rights. Indeed there is no reason why the market cannot play as much of a role, if not a greater one, than it plays in the allocation of land. Creating property rights in radio spectrum would result in its more efficient utilization while at the same time allowing the value of these rights to

serve as a tax base, similar to the treatment of land. None of this would preclude some government control over these rights, just as government maintains a degree of control over land utilization. The credibility of the concept of private property rights was enhanced when President Bush, in his January 1989 budget message, proposed the sale of unassigned radio frequencies as a method for raising revenue to reduce the federal budget deficit.

II. The Nature of Radio Frequency Spectrum

The radio frequency spectrum (henceforth called spectrum) is that part of the electro-magnetic spectrum useful for transmitting electric and magnetic waves through space. It is measured by frequency - the number of oscillations per second of the electric and magnetic fields which travel through space at the speed of light, 300 million meters per second. It includes frequencies as low as 10 kilohertz (10,000 cycles per second) and as high as 300 gigahertz (300, 000,000,000 cycles per second). Different parts of the spectrum have very different characteristics concerning such things as the distance the signal will travel, line of sight vs. skywave propagation, potential for interference by atmospheric or ionospheric conditions and the ability to travel through such obstacles as mountains, buildings, or even rain.

The demand for spectrum is growing as existing technologies expand the number of users and as new technologies develop in ways undreamed of a decade or two ago. There are many substitutes for spectrum as an economic resource, e.g., submarine cable and cable television. Transportation in some ways can also be a substitute for spectrum.(1)

The supply of spectrum, like the supply of almost all other resources is limited. However, just as we have increased the use of land along both the intensive and extensive margins, similar increases occur in the use of spectrum.

New technologies have facilitated a more intensive use of existing spectrum. Newer techniques, e.g., single sideband as compared to conventional AM transmission, lower noise and more selective receivers, and alternating antenna polarities allow more users to be accommodated in a given amount of spectrum. A relatively new technique called packet radio allows packets of data to be sent in short bursts from an originating station to one or more receiving stations. These receiving stations will send back acknowledgment of error-free reception. The transmitting station will repeat the packet until all receiving stations have received an error-free message. This permits many users to share a common frequency and is thus much more spectrum intensive than voice or video transmission. Although the technique is only a few years old, packet radio is already widely used in commercial applications, government (both military and non-military), and the amateur radio communities.

The use of spectrum is also being expanded along the extensive margin. New techniques are being used to expand the lower limit of usable spectrum, i.e., the use of very low frequencies for communication with submerged submarines. However, the extensive margin is being expanded primarily at the upper end of the usable spectrum. Satellite transmission in the 12 Gigahertz range is a recent example.

Contrary to popular belief, spectrum is not a public good. A public good has two characteristics. First, it involves non-rival consumption, i.e., the use by any one user does not diminish the utility of the resource to other users. Second, it involves non-exclusion, i.e., one cannot be excluded from receiving the benefits based on payment for its use.(2) Spectrum possesses neither of these characteristics. There is rival consumption in that use of spectrum by one user may interfere with the ability of other users to use the same frequency, adjacent frequencies, or even far removed frequencies. (3) It is also possible to exclude users from the spectrum. This may require a governmental authority to assign rights to the spectrum, set rules for the use of spectrum, monitor the use of spectrum, and enforce the rules. But this is no different from the government's role in the management of other resources. Is there any difference between the government's role in spectrum management and the role of the police and the courts in excluding squatters from private land or the role of zoning boards in enforcing land use statutes?

Radio frequency spectrum does, of course, involve extensive externalities. It is the job of the spectrum manager to take these externalities

into account in the spectrum allocation process. This can be done by regulation or by in some way internalizing these externalities. Although a difference in degree may exist, in regard to externalities the job of the spectrum manager is no different than the job of the zoning board. Both have to minimize the negative effects of these externalities either by the enforcement of regulation or by encouraging the affected parties to negotiate a solution to the problem and thus internalize these externalities.(4)

Radio frequency spectrum is managed today almost exclusively by government planning. International agreements (treaties) are administered by the International Telecommunication Union (ITU), a branch of the United Nations headquartered in Geneva, Switzerland. These international treaties are negotiated at periodic World Administrative Radio Conferences (WARC). The latest WARC in 1979 left many unanswered questions, e.g., the desire of many developing countries to have their own commercial satellites, while most of the available orbital slots are already occupied by satellites of the developed countries.

Spectrum management at the domestic level is accomplished through various government planning agencies. In the United States this is done by two agencies. The Department of Telecommunications Management (DTM), a branch of the Administration, has responsibility for government uses of the spectrum, while the Federal Communications Commission (FCC) has jurisdiction for all non-government uses.

Many people believe that spectrum has unique characteristics which preclude the use of market forces in determining its allocation. It is believed by some analysts that spectrum has some properties of a common property resource (See Melody, 1980). For such common property resources as fishing rights or oil rights there will be a tendency for inefficient resource use unless unilateral control is exercised, i.e., government planning or a system of mutual cooperation. This analogy is erroneous. A user of the spectrum may preclude someone else from using that spectrum at that moment; it does not however, in any way, deplete the availability of spectrum for future users. A much better analogy would be to compare the management of spectrum to the management of land.

In western democracies decisions concerning the allocation of land are made at two levels. Government authorities set the rules of the game in the form of national, regional, and local land use plans, a system of taxing both the stock value of the land and the flow of income derived from the land, and rules concerning the treatment of externalities generated by the use of such land. The enforcement of such rules is the responsibility of various governmental bodies, e.g., environmental agencies, zoning boards, and the courts (See Denman and Prodane, 1972). Within the context of the above constraints, the allocation of land is determined by market decisions.

Radio frequency spectrum is similar to land and can be allocated in a comparable manner. It is the role of government to define the nature of the resource and the particular property rights attached to the resource, to create a method to assign (sell) these property rights to the highest bidder, and to create a mechanism for monitoring the use of the resource to insure that no user violates the property rights of others. Within the constraints outlined above, owners of spectrum rights would be free to use their rights in any manner they choose including the ability to sell these rights to others, either in total or by subdivision.

There are, of course, technical problems which must be overcome if such a system is to be implemented. Although there are considerable difficulties involved in defining the property rights and setting up an appropriate monitoring and enforcement system, such problems are solvable. Indeed, once such a system is created, its administration will be much less complicated than land administration because the authority for management of radio frequency spectrum can be assigned to a single federal government agency.(5)

III. A System of Spectrum-Use Rights

Devanny, et al (1980) identify four essential characteristics necessary in property rights to a resource so that the resource can be allocated to its most productive use. These characteristics are:

(1) Exclusion - the owner is free to use the resource without restrictions and can exclude

others from using it except where authorized by the owner.

(2) Costs of Exchange and Enforcement - Rights are freely exchangeable at low cost relative to their value (Devanny, et al, 1980, p. 11).

(3) Externalities - Any definition of property rights in spectrum must address the question of internalizing externalities when possible and minimizing the enforcement and exchange costs of such transactions (Devanny, et al, 1980, p. 12).

(4) Flexibility versus Certainty - The definition of a property right requires a statement of what rights may legally be undertaken and what rights are prohibited. The more property rights permitted the right holder, the more flexibility he has in maximizing his return for these rights. On the other hand, prohibiting certain uses of these rights will create more uncertainty on the part of others who may be affected by the exercise of these rights. Clearly trade-offs are necessary to achieve the most desirable mix of flexibility and certainty. (Minasian, 1975, p. 228).

The present system of regulation defines rights to spectrum by specifying what one can do at the input end, i.e., what one can do with a radio transmitter. The rights granted by a license specify transmitter power, antenna height, gain, location, and polarity, modulation techniques and other technical standards. Most proposals for the creation of property rights to radio frequency spectrum suggest that such rights be defined as output rights, i.e., the right to be able to receive transmissions in a given segment of the spectrum and in a given geographical area with a given signal intensity at the receiver. The rights of others who use adjacent spectrum or the same spectrum in adjacent geographical areas would be defined in terms of the maximum signal level (interference) they are permitted to create at the receiver locations of other spectrum users. Thus the emphasis is shifted from input (transmitter) specification to output (receiver) specifications.(6)

Devanny, et al, define the rights to spectrum in terms of three variables: time, area, and spectrum. They refer to this as the TAS System.

Time rights can be defined as 24 hours per day in perpetuity to any small fraction of time. Some present licenses are restricted as to their time rights to the spectrum. Some AM broadcast licenses allow only daytime operation because of the tendency of radio energy at that frequency to travel long distances after dark due to ionospheric bounce (skip) and thus create interference hundreds or even thousands of miles away. Other AM broadcast stations are required to use lower power or change their antenna patterns after dark. Time rights would be transferrable in part or in total. For example: A rights holder could transfer his rights for the period 6 A.M. to 6 P.M. in perpetuity or he could transfer his rights for 24 hours per day for 30 days at which time the rights would revert to the original holder.

Area rights allow the holder, subject to time and spectrum constraints, the exclusive rights to radiate as long as the field strength of such radiation does not exceed a specified level outside his area. It also gives him the right to be free from the radiation of others (interference) above this same specified level. Owners of adjacent area rights would be free to negotiate with each other so that one party is permitted to create a higher level of radiation in the other's area (7). The holder of area rights would also be free to merge their operations to minimize problems of interference in adjacent areas.

Spectrum rights give the holder exclusive rights to radiate within a band of frequencies defined by an upper and lower limit, subject to the time and area constraints. Such rights carry the limitation that the measured field strength of the signal must be no greater than some specified level on other frequencies and also the right to be free of such interference from holders of other spectrum rights above this specified level. Holders of adjacent spectrum rights would be free to negotiate with each other the permitted level of interference or to merge operations if desired.

Once time, area, and spectrum are defined, we have a useable TAS package. The exact dimension of such packages will require detailed economic and engineering studies. If the packages are defined in segments which are too small, the costs of interference to adjacent areas and spectrum are increased. Also, it may be economically inefficient to the user. An example is Multi-

point Distribution Service (MDS). These are microwave channels which are used primarily for pay television in urban areas. Until recently in most cities only one MDS channel was available. Recently the FCC allocated additional channels in most cities which allow the creation of a multi-channel system (MMDS). Such a system of wireless cable with as many as 20 channels could be economically viable in competition with a traditional (wired) cable system.

On the other hand it is desirable that the TAS packages not be too large. Large packages may preclude the small user and create concentration of monopoly power.

Economically and technically optimal initial TAS packages would minimize the subsequent transactions costs involved in market exchanges. The cost of obtaining the information needed to create optimal TAS packages would be substantial. This should not deter the creation of such a system. TAS packages could be created to approximate optimality and then market exchanges would move these packages closer to optimality. In any case this is a dynamic process with the optimality changing over time.

IV. An Operational System

Under one possible system of spectrum allocation, an Administrative Agency, presumably the FCC, would draw up definitions of TAS packages for all radio spectrum. (8) Certain parts of the spectrum would be reserved for government use. However, the market value of such government spectrum would eventually be determined so that meaningful cost-benefit analysis could be conducted to determine the optimal amount of spectrum for governmental use.

Once the TAS packages were created, they would be auctioned off to the highest bidder. The payments for each TAS package would go into the national treasury. The rights-holder would then be free to use them in any way they desire or to sell them in whole or in part to others. The agency would investigate complaints of interference from the users. Where the complaint is found to be valid, the offending party would be required to pay damages to the injured party, as well as a fine to the spectrum management agency which would cover the administrative costs of enforcement. Where the complaint is found to be invalid, the complainant would be required to pay a fine approximating the cost of the investigation. (9) Thus the process of enforcing property rights for TAS rights holders would be fully self-supporting.

Once all TAS packages have been auctioned off, such spectrum would become private property. These packages would be similar to packages of land. Each parcel of land is somewhat unique and thus has a site value. Likewise each TAS package has some unique properties and thus can also be said to have site value.

Ricardian rent theory states that economic rent is derived from differential advantages of one piece of land over another. A parcel of land which is right on the margin of usefulness has an economic rent of zero. A parcel of valuable land, on the other hand, has an economic rent equal to the difference between its value and that of the marginal land. This economic rent is a function of the unique qualities of the land as a productive resource. A tax on pure economic rent, that is on site value and not on the improvements to the land, will be borne by the landowners and cannot be shifted.

Each TAS package of spectrum rights also has unique properties. Thus each package has a site value equal to its economic rent. Some TAS packages which are at or near the margin of usefulness will have little or no economic rent. Some TAS packages will be sub-marginal and have zero economic rent. It is important to emphasize that because a spectrum rights holder makes a large investment in equipment necessary to use his piece of the spectrum does not increase the economic rent. Economic rent depends only on site value, not on improvements made by the rights holder. On the other hand, as new demands for spectrum occur and new technologies make more intensive use of the spectrum possible, site values will increase, but this must be looked at independently of the investment made by the rights-holder.

A national tax could be imposed on the site values of TAS packages. This tax can range from a Henry George tax equal to one hundred percent of economic rent to some fraction of economic rent. In a world of perfect certainty where any changes in site values are anticipated, it would make no difference whether the tax is

zero percent, one hundred percent, or anything in between. The value of a TAS package and thus the revenue derived by government from an auction is the present value of a future stream of economic rents. Thus a fifty percent tax on economic rent in perpetuity would cause the present value of the package to be cut in half.

The main difference between a low tax rate and a high tax rate is who will bear the risks and rewards of changing site values. For example, with a tax of zero, buyers of TAS packages would pay a high initial price and the rights holder would bear all the risks and receive all the rewards from unanticipated changes in site values. On the other hand, with a tax equal to one hundred percent of economic rent, the initial price of each package would be zero with all risks and all rewards going to the government.

Since the bulk of investment in technological development to extend the intensive margin of radio frequency spectrum is made by private users of the spectrum, it is appropriate that they bear the bulk of the risks and receive the bulk of the rewards from changing - and hopefully increasing - site value of spectrum. However, some of the innovations come through public investment. Government, particularly military and space research, research in non-profit institutions (e.g., universities), and even innovation by the amateur radio community, are all examples of investment by society. Therefore it is appropriate that some of the risks and some of the rewards be shared by society.

In any event the tax should be set at a level which would allow society to share in the growth of the value of these spectrum packages and yet not be so high as to discourage investment in the development of new uses of the spectrum. The tax rate however must not be so low as to allow rights holders to stockpile spectrum and keep it out of productive use.

The continuing stream of tax revenue should be more than sufficient to fund the operation of the spectrum allocation agency. This agency would have three main functions. Monitoring and enforcing property rights, as previously discussed, should be self-supporting. Second, the agency would engage in on-going research to develop better methods of defining and measuring uses of the spectrum including the creation of new TAS packages at the extensive margin of the spectrum which was previously sub-marginal. Finally, the agency would become a national assessment board to constantly monitor the site values of TAS packages. Although this sounds like a complex procedure, it may in fact be much simpler than the process of land assessment as now carried out by thousands of local and county tax assessors.

V. A Working Proposal

The system outlined in the previous section would involve a number of serious complications in its implementation. From a technical and economic standpoint, simultaneously defining all TAS packages would be an enormous task. The problem of simultaneously defining a set of all TAS packages to even approximate optimality would be nearly impossible. Thus, from a technical standpoint, it would be desirable to create TAS packages in small blocks. As blocks to TAS packages are created, they would be privatized through an auction process. From these initial TAS packages information would be generated which would help to better define future TAS packages - and indeed determine whether to continue privatizing spectrum.

Although the technical and economic problems involved in privatizing spectrum are considerable, the more serious constraints involve social and political factors. For those parts of the spectrum with international implications new WARC treaties would have to be negotiated. Since the vast majority of participating nations are much less committed to market allocations than we in the United States are, considerable opposition to privatizing spectrum can be expected.

Similar opposition can also be expected at the domestic level. There is a (mistaken) belief in Congress and elsewhere that the "airwaves" belong to the public (10). Much of the political opposition to privatizing radio frequency spectrum is related to the use of spectrum for broadcasting and a fear that privatization would hinder First Amendment rights to free speech. The First Amendment states, "Congress shall make no laws...abridging the freedom of speech, or of the press..." Opponents of the privatization of spectrum argue that this would somehow hinder

the freedom of speech of broadcasters.

One could argue that the present system of regulation hinders First Amendment rights and that the creation of private property rights in radio spectrum would enhance the rights of free speech. Because the amount of radio frequency spectrum is finite, while no such limit exists for newspaper publishing, radio and television broadcast licenses must be treated differently from newspapers to preserve First Amendment rights.

It is the demand, not the supply, which limits the number of television stations or newspapers. Indeed, under a system of private property rights, the number of television stations in a given market could expand to meet demand by transferring rights from other spectrum or by negotiating for area rights with owners of TAS packages in adjacent areas. Under the present system, the number of television stations in a given city is fixed. It could be that the number of over-the-air television stations will, in fact, decrease in the future as more homes have access to television programming through alternative technologies, i.e., cable or direct broadcast satellite. At the margin some of the existing spectrum now allocated for television broadcasting will be shifted to more productive uses. Under the present system of block allocation, this is a much more cumbersome process.

Although theoretically most of the spectrum can be privatized, as a practical matter this must be done in small segments for selected parts of the spectrum and for specific uses. First, it would be wise to eliminate from initial consideration those parts of the spectrum with strong international implications. Spectrum below approximately 50 megahertz has the potential for transmission over long distances through ionospheric bounce. From a technical standpoint, there is a great deal of uncertainty however. The extent of such propagation varies with the time of day, season of the year, the stage of the sunspot cycle, and the amount of electro-magnetic activity on the sun. These complications would make the task of defining TAS packages and enforcing the rights of TAS rights-holders very difficult. Eventually these problems could be overcome, but it would be desirable to first have some experience with that part of the spectrum where propagation characteristics are more certain.

In addition to the technical problems, there are also considerable political problems involved in privatizing radio frequency spectrum with international potential. For this reason, that part of the spectrum with potential for satellite communication should also be eliminated from initial consideration. If the two zones were eliminated, initial privatization would occur in the range of spectrum between 50 megahertz and 3 gigahertz (3000 megahertz).

Initial consideration for privatization should also exclude broadcasting. First, there is a technical problem in that, unlike most other spectrum uses, the transmitters and receivers are not under common ownership and control. This would somewhat complicate the problem of defining property rights but it could easily be solved. In addition, there is the above-mentioned belief that First Amendment rights would be somehow interfered with by privatization. Therefore, it would be practical to exclude broadcasting from initial consideration.

The first implementation of private property rights might include land-mobile services and pay television. In a notice of proposed rule-making dated June 10, 1985, the FCC proposed sharing part of the UHF television band with private land mobile radio services (11). This situation was created by the present system of block allocation made when the FCC originally assigned the UHF television channels. Because of improvements in receiver technology and because the demand for UHF television has not been as great as expected: "All existing UHF stations could be accommodated in less than half of the present UHF band thereby freeing a significant portion of the spectrum for expanded broadcasting or other services (See Jackson, 1980, p. 39).

Another area where some reassignment of spectrum is occurring is the regulation by the FCC permitting the holders of Instructional Television Fixed Service (ITFS) licenses to lease part of their excess channel capacity to Multichannel Multipoint Distribution Service (MMDS) users for creating multichannel wireless cable. This is another area where the creation of private property rights could be easily accomplished, with a minimum number of problems, and with significant advantages for more efficient resource allocation.

VI. Summary and Conclusion

It is the contention of this paper that certain segments of the spectrum and certain uses of such spectrum could be selected for initial privatization. Which segments to use initially would be based on further study along technical and economic grounds. Land-mobile service and MMDS pay television have been suggested as initial candidates; certain common carrier services in the microwave frequency range also came to mind.

Once these spectrum segments are selected, TAS packages would be defined. Auctions would then be held to allocate these to the highest bidder - presumably those who value the package highest - with the proceeds of the auction accruing to the public (the Treasury). The owners of these TAS packages would be free to use them in any way desired with the only constraint being the limitation on interference they are permitted to create for other users of the spectrum. They would also have the right to be free of such interference from others. Their rights in total or in part could be freely transferred to others.

A system of assessment would be set up to determine the value of the economic rent (site value). A tax would then be imposed equal to some fraction of these economic rents. (12)

Finally, a system of enforcement, probably as part of the present FCC, would be set up. This agency would respond primarily to complaints of interference from spectrum users. Where a user of the spectrum violates the property rights of others, a fine would be imposed as well as a payment to the injured party. Where a complaint is found to be erroneous, a fine would be imposed on the complainant, as well as payment to the party wrongfully accused. Through the fines collected, this agency could be self-supporting.

The experience of creating private property rights in selected parts of the spectrum would enable us to gradually extend privatization to other parts of the spectrum. Eventually, the technical, economic, social, and political problems necessary to expand privatization to that part of the spectrum with international overtones and to broadcasting must be overcome.

The potential benefits of such a system are substantial. A more efficient allocation of resources would take place. No longer would users of the spectrum have a tendency to overuse spectrum while economizing on the use of other resources. No longer would block allocation create parts of the spectrum which are underutilized, e.g., part of the UHF television band and ITFS channels, while other users are denied needed spectrum, e.g., land-mobile services, public safety agencies, and wireless cable (MMDS).

A system of private property rights in radio frequency spectrum would also have beneficial effects on the distribution of income and wealth. No longer would licensees be able to stockpile spectrum and keep it out of productive use. No longer would licensees be able to create monopoly rents by restricting entry to their markets.

It is the authors' contention that the benefits from the creation of private property rights in radio frequency spectrum are so substantial as compared to any risks, that as a society committed to private property rights for most other resources, we must also extend the benefits of the market to radio frequency spectrum. Any opposition to these proposals comes mainly from a lack of understanding of its implications. The public and the Congress must be educated as to the benefits of such a system. Because the potential benefits are so great and the risks small-why not go ahead with a system of limited implementation? The benefits would be so apparent that it will then be easy to create a mood for further expansion of private property rights in radio frequency spectrum with eventually most radio spectrum privately owned.

The Federal Communications Commission under former Chairman Mark Fowler made considerable progress toward deregulation and open entry into broadcasting and other spectrum use. Many of the regulatory changes have moved us closer to a system of private property rights in radio spectrum. These include the creation of low power television stations, the creation of multichannel MDS and the proposed rulemaking to allocate part of the UHF television band to land-mobile services.

Dennis Patrick assumed the chairmanship of the FCC in 1987. Mr. Patrick told the Senate

Commerce Committee that he would place the same reliance on the competitive marketplace as did his predecessor. "And while I believe that markets and competition will usually serve consumers better than regulation, it is important to keep in mind that competition and deregulation are only a means to our ultimate end: the promotion of consumer welfare." (13)

Establishing private property rights in radio spectrum is a win-win situation. Not only would the efficiency of the market be enhanced, but revenue raised from the initial sale and subsequent taxation of these rights could serve as a significant revenue source for the federal government.

Footnotes

1 Transportation in many cases can also be a complement to uses of the spectrum and thus increase its demand.
2 The term "public good" used above is based on a narrow definition used in most public finance textbooks. See Aronson, 1985, pp. 26 and 599.
3 Interference with users of adjacent frequencies will occur when the band width of the transmitter is such that the level of noise (interference) on adjacent frequencies exceeds some maximum level or where the receivers do not have the ability to discriminate between the desired frequency and adjacent frequencies due to the tendency of transmitters to emit harmonics, i.e., a signal on multiples of the fundamental frequency. Interferences can also be created through a problem of beat frequencies, i.e., a tendency of two signals to beat against each other and create a beat (interference) on the sum or difference of the two frequencies. All of these sources of interference can be diminished or eliminated with proper engineering techniques including filtering at the transmitters and receivers.
4 Both the zoning board and the spectrum manager must also take steps to fully exploit all positive externalities.
5 The Supremacy Clause of the Constitution states that actions of the Federal Government supersede inconsistent or contradictory actions of state or local governments. The FCC recently issued orders partially superseding the powers of local governments in the regulation of amateur radio towers and consumer satellite dishes.
6 Milton Mueller contends that there may not be a great deal of difference in the two systems as input specifications make assumptions, about output and vice versa. See Mueller, 1983, pp. 95-96.
7 This is a classic example of the Coase Theorem. See Aronson, 1985, pp. 5254.
8 Negotiations with other countries through the ITU would be needed before allocating those parts of the spectrum with international implications, i.e., frequencies below 50 megahertz and microwave frequencies used for satellite transmissions.
9 The complainant may also be required to pay something to the TAS rightsholder they unjustly accused - a form of libel.
10 A prominent writer on electronic communications argued that the airwaves should be public because it involves "the air that is essential to life, the air we breathe." This is nonsense. Electromagnetic propagation has nothing to do with air. Indeed, radio astronomy, communication satellites, and moon bounce propagation are evidence that electro-magnetic energy can travel through space as well, if not better than, through an atmosphere. Les Brown "Fear of Fowler" *Channels* January/February 1982 (p. 36). Quoted in Edwin Diamond, et al, 1983, p. 65.
11 Federal Communications Commission, Notice of Proposed Rulemaking "In the Matter of Further Sharing of the UHF Television Band by Private Land Mobile Services" Released June 10, 1985.
12 An anonymous referee suggested that an alternative method of capturing the economic rent from these packages be a surcharge on the Federal Income Tax due on each package, with a minimum tax to prevent stockpiling. We find this suggestion interesting and believe that further study might show implications not only in the area of rights to radio frequency spectrum, but also in such areas as common property rights, e.g., fishing rights and the process of attempting to internalize externalities.
13 Quoted in *Cablevision* (May 1987) p. 4.

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