1981

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Recommended Citation
Wihlborg, Clas G., and Per Magnus Wijkman. "Outer space resources in efficient and equitable use: New frontiers for old principles." *Journal of Law and Economics* (1981): 23-43.

OUTER SPACE RESOURCES IN EFFICIENT AND EQUITABLE USE: NEW FRONTIERS FOR OLD PRINCIPLES*

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SPACE is the common property of mankind. Traditionally, access to common property resources such as the oceans has been open and free. This is appropriate for resources that are plentiful. At first glance, space appears to be not only abundant but infinite. However, future demand for space resources may soon make them scarce in the sense that an allocation mechanism will be needed for their efficient utilization. Satellites already perform traditional and new services using outer space resources, and plans for industrial ventures in space are under way. Space activities compete with more earthly activities for use of the scarce electromagnetic spectrum.

This paper demonstrates how the general principles of efficient markets easily can be extended to space resources. In fact, the market mechanism is particularly well suited to achieving efficient use of these resources given the difficulty for a central authority to obtain the necessary information. The paper is inspired by two seminal articles by R. H. Coase on the organization of economic activity.[1] Our application is one of many

* The authors thank William Baumol, Peter Bohm, and Mats Bohman for valuable comments. This is a revised and expanded version of a paper presented at the Conference on Space Commerce: New Options for Economic Growth, November 1978, Sponsored by the Salomon Brothers Center for the Study of Financial Institutions and the Graduate Center for Applied Science, New York University, and organized by the American Institute of Aeronautics and Astronautics. The second author acknowledges financial support from the Pew Memorial Trust and the Department of Commerce, NOAA, Office of Sea Grant, Grant 04-8-M01-149.

R. H. Coase, The Federal Communications Commission, 2 J. Law & Econ. 1 (1959) [hereinafter cited as Coase, FTC]; *id.*, The Problem of Social Cost, 3 J. Law & Econ. 1 (1960). Together with William Meckling and Jora Minasian, Coase wrote Problems in Radio Frequency Allocation (Rand Corp. 1963). Although this manuscript remained unpublished, the coauthors later published two important contributions. See William H. Meckling, Management of the Frequency Spectrum, 1968 Wash. U.L.Q. 26; a Jora R. Minasian, Property Rights in Radiation: An Alternative Approach to Radio Frequency Allocation, 18 J. Law & Econ. 221 (1975).

possibilities; the same reasoning could be applied to other common property resources.

Section I defines the "orbit spectrum resource" commonly referred to in discussions of the allocation of space resources and argues that it in fact consists of two separable resources which should be allocated separately: the physical orbit "slots" and the electromagnetic spectrum. The section also emphasizes that different techniques for utilizing space can substitute for each other and that space resources and earth resources are substitutable.

Section II argues that establishing *marketable, divisible, indefinite* user rights for the *totality* of space resources and well-defined enforceable *liability rules* for interference should be sufficient for efficiency in most uses of space resources. This conclusion is valid in spite of the frequent occurrence of external effects.

Section III considers the contribution that an international authority can make to the efficient use and equitable distribution of space resources. Efficiency aspects generally can be separated from equity aspects when conditions for efficient markets are fulfilled. The section therefore argues that once certain conventions defining market behavior have been adopted the prime task of an international authority is to distribute rents from space resources. Section III compares the current first-come, first-served regime with a squatters'-rights regime, an auction regime, and a current proposal to carve up space resources and distribute the parts among nations. The current regime is often equated with a squatters'-rights regime, but we argue that it differs fundamentally because the property rights that accompany the user rights are too incomplete for efficient markets to exist. The current regime also bureaucratically constrains the use of some space resources.

I. Is Space Scarce?

The increasing usefulness of outer space is the basis for its current or potential scarcity. This section describes briefly some of the services provided and the ways in which space is utilized.

Satellites can serve as unmanned relay stations (for example, Comsat and Landsat) as well as manned industrial estates (for example, the late Skylab).[2] We consider mainly the former use but our analysis is valid for

[2] Relay stations provide communication services and remote sensing services. Communication satellites are used for radio, television, telephone, and telex services. Remote sensing satellites collect a wide range of information about our planet such as meteorological data, ocean and coastal zone data, environmental data, and earth resource data. Both types of satellites are in growing demand for commercial use and as public goods. Space platforms have not yet been put to commercial use. They appear to be commercially feasible for

both kinds, because each requires both a *location* in space and a *means of communication* with earth.

Wireless communications on earth can cover only a limited geographic area due to the curvature of the earth away from the line of sight followed by most frequencies.[3] For longer distances, relay stations must be built or shortwave signals of unreliable quality used. Consequently, cable transmission of signals is often more economical than wireless for long distance communications, especially for transmitting over large bodies of water. Satellites now provide yet another alternative. They receive straight-line signals from earth and redirect them back to another point on earth with a degree of precision that is determined by their on-board hardware. Satellites can provide many services at lower cost than can earth-based relay stations, cables, or shortwave frequencies.

Current technology allows signals to be sent directly from a specific transmitter to an individual receiver (for instance, telephone, telex, or computer terminal) provided that both are equipped with the appropriate hardware. Large civilian and military organizations have found such point-to-point (or fixed) services to be especially useful.[4] However, if the market is sufficiently large in a given area, use of collective rather than individual receiving equipment reduces reception costs due to economies of scale. Earth stations receive signals from satellites and retransmit them to television, radio, or telephone sets via cables or wires. Broadcasting and fixed services make different demands on the electromagnetic spectrum and on equipment on earth and in space.

Satellites may be geostationary, that is, remain in a fixed position relative to earth, or they may circle the earth in polar orbits or in other orbits. Geostationary orbits are especially valuable for those services that require twenty-four-hour coverage of a given point on earth. Navigational aids, some kinds of computer-data transmission, and solar-energy stations are examples of services for which geostationary satellites are vital. It is possible, however, to replace one geostationary satellite by two or more

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certain activities, for instance as solar energy stations, and for energy intensive activities (aluminum production) and engineering under gravity-free conditions (ball-bearing construction and crystal growth). Some of these uses were first suggested by Gerard K. O'Neill in his pioneering work, The High Frontier: Human Colonies in Space (1976). See also Delbert D. Smith, Space Stations: International Law and Policy (1979).

[3] For instance, FM radio signals follow line of sight, while shortwave signals bounce off the ionosphere and back to earth at unpredictable times and places.

[4] Traditional broadcasting services such as radio and television can be sent also as fixed services. Proposals for a system of three television satellites to link the five Nordic countries in a common television area are currently being considered by the Nordic governments. Viewers in Iceland, for example, could pick up Danish or Swedish programs directly by adding supplemental receiving equipment to their sets. Some commercial television stations in the United States currently employ satellite-cum-cable transmission.

nonstationary satellites. Such a substitution increases the equipment costs but may reduce other costs.[5]

The equipment on satellites in space may be such that signals are directly reflected by the satellite to earth (real time) or the satellite may store information on board for delayed (rapid) transmission. Alternative techniques and orbits are therefore available to provide a specific service. For example, the user of a nonstationary satellite might construct a number of expensive earth stations under its orbit, or he may invest in on-board equipment that stores information for rapid transmission when the satellite passes over a single earth station. The user weighs the inconvenience of delayed transmission and the cost of equipping and launching a satellite with the necessary storage facilities against the cost of building a sufficient number of earth stations for real-time transmission.

Two factors constrain the capacity of these orbits and cause space resources to be scarce. First, there is a definite *physical limit* to the use of geostationary orbits. Slots are located in a "tube" with a total length of about 150,000 miles. Satellites are never absolutely stationary. If each satellite "wanders" at most 100 miles horizontally,[6] the geostationary orbit could provide 1,500 orbital slots along its length, each with a zero probability of collision. Since only 200 satellites are expected to be in the geostationary orbit by the end of 1981, congestion does not now appear imminent.[7] However, available slots are not perfect substitutes for each other. Telecommunications are highly concentrated to flows between a few regions on earth and satellites for communications between two given points on earth have a preferred location.[8] Thus, the demand for satellite

[5] Orbiting satellites are affected by centrifugal force (determined by their speed) and by gravitational force (determined mainly by their distance from earth). When these forces offset each other, a satellite can remain in orbit with its engines turned off. A satellite that is injected into orbit at the speed with which the earth rotates around its axis stays constant relative to earth if it is on a plane through the equator. It can turn off its engines and remain in orbit if it is 22,240 miles from earth. If it is placed in a lower (higher) orbit, it must be injected at a higher (lower) speed than the earth's rotation in order to offset its greater (lesser) gravitational pull, and consequently it will not be geostationary. The speed at which a satellite is injected into orbit is determined by the power generated when it is launched. The greater the power, the greater the launching costs. Thus, different orbits involve different costs, but they also have different characteristics making them appropriate for different services.

[6] See U.N. Committee on the Peaceful Uses of Outer Space, Physical Nature and Technical Attributes of the Geostationary Orbit, U.N. Doc. A/AC 105/203, para. 18 (29 August 1977).

[7] New satellites are currently being launched at the rate of 20 per year, and 200 are expected to be in the geostationary tube at the end of 1981. See U.N. Committee on the Peaceful Uses of Outer Space, *supra* note 6.

[8] The demand for telecommunications has a high elasticity with respect to per capita income. At given levels of per capita income the number of messages exchanged between two regions increases exponentially with the size of their populations. The demand for

slots in the near future will probably be concentrated on the arc of the geostationary orbit over the North Atlantic. This suggests that congestion may occur in the foreseeable future, especially since the number of possible uses of satellites can be expected to increase as well as the number of users.[9]

Satellites in polar orbits, passing over the poles while the earth rotates around its axis, observe a given point on earth at fixed intervals. Both the frequency with which an area is observed and the size of this area depends on the satellite's distance from earth. More frequent observation requires smaller orbits and therefore covers smaller areas. Satellites in smaller orbits require greater injection speeds, which entail higher launching costs. Some polar orbits are especially well suited to maritime satellites, others to earth resource satellites, and so on. One might assume that polar orbits are more plentiful since they are not confined to a single distance from earth as are geostationary orbits. However, just as geostationary orbital slots differ, so do polar orbits. Each has different properties and any combination of particular properties is potentially scarce because it generates different economic benefits and costs when performing different services. To repeat this important point, since different orbits or slots are not perfect substitutes for most uses, they are potentially scarce.

The second constraint on orbit capacity is imposed by the *electromagnetic spectrum*. Satellites transmitting within a certain area compete for use of the spectrum. They compete with each other and with terrestrial communications and even with intergalactic transmissions. Thus, the constraint on the use of orbits given by the use of the electromagnetic spectrum is a constraint common to *all uses* of this resource. The spectrum resource is already so congested on earth that the international community faces major problems of allocating frequencies. The development of satellite technology leads to yet another claim.[10] So far,

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telecommunications consequently will be greatest in densely populated regions with high per capita income.

Just as the strength of rays from the sun depends on the angle with which the rays hit the earth, the quality of radio transmission between a satellite and a point on earth depends on the angle with which the frequency waves hit the earth. Less energy is needed to transmit between relatively close points, and the degree of precision required in transmission increases with the angle. Together these considerations imply that a satellite relaying between two given points has a preferred position in the orbit—preferred because it is more economical than other positions.

[9] Assuming that 150 satellites are already above the North Atlantic and that 15 more will be parked there each year, the available 375 slots will be filled 15 years after 1981. Inactive satellites can be removed from the geostationary orbit.

[10] Congestion or overuse of the electromagnetic spectrum appears as interference—the jamming of one transmitter by another or the spillover of one transmission into others. It is obvious that if two senders use the same frequency with the same strength at the same time

the problem has been "solved" by assigning certain bands (4, 12, and 16 GHz) for satellite communication. This has created the so-called orbit-spectrum resource. This limitation on frequency use constrains the number of satellite slots in geostationary orbit since it determines the minimum physical distance between satellites necessary to avoid interference and jamming of communications in the assigned frequencies. Thus, under the current regulatory system the scarcity of space resources is made by man rather than by nature. The orbit-spectrum resource (that is, the number of slots) can be expanded by increasing the number of bands available for satellite communications. Of course, this occurs at the expense of other potential uses of those bands.

This elementary review of satellite technology allows the following conclusions:

1. The orbit-spectrum resource is not a single resource in fixed supply but a composite resource made up of the electromagnetic spectrum and satellite orbits. Each of these in turn consists of several dimensions.
2. The electromagnetic spectrum is already congested, and parts of the geostationary orbit will be congested in the next decade.
3. More intensive exploitation of the resources can be achieved by applying more capital and labor to the natural resources and by a more efficient combination of the various components of that resource: band width, place, time, and strength.
4. Satellite services can be replaced by services which use earth resources alone.

Thus, we face a wide range of substitution possibilities for both inputs and outputs which, if properly exploited, can increase the supply of the resource and divert demand for it to alternatives. The important questions then are what we mean by efficient use of space and what mechanism achieves efficiency given these substitution possibilities.

II. Properties of Efficient Markets for Space Resources

This section argues that markets allocate rights to use orbit-spectrum resources more efficiently than do the nonmarket mechanisms currently in use.[11] It considers three aspects of efficiency. First, efficiency means

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and at the same place, neither will be clearly heard. But it is not so obvious what the solution to the problem of interference is since the resource is not easily divisible and external effects are therefore inherent in its use. It is interesting to note that it was his prior study of federal regulation of the airwaves that inspired Coase's classic article on the treatment of external effects, Coase, Social Cost, *supra* note 1.

[11] We cannot prove that a market system is most efficient under all circumstances. We simply point to its advantages relative to the centralized bureaucratic system for allocating current user rights.

that a resource is allocated so that the marginal unit cannot be reallocated to another user without lowering value added. Second, an efficient system moves towards a new efficient allocation in the above sense after any disturbance such as an increase in demand or a reduction of production costs. These two aspects of efficiency will be denoted as *partial* efficiency in the markets for space resources. Third, and more general, an efficient system provides incentives for investment or research in new activities when they are expected to produce higher value added than do current activities.[12]

As an economic resource, space consists of orbital positions and frequency bands. Efficiency requires that these can be combined freely. Currently they are sold as a unit with fixed coefficients. This is like assigning a radio station on earth a specific piece of real estate for a transmitter together with a frequency. Separate markets in frequency bands and orbit positions make it possible for all users of space locations and frequencies to trade the two separable economic resources until a Pareto-optimal situation is reached. In such a situation no user can change location and frequency without paying more than the potential gains generated by the new combination. Note, however, that in order for the markets for the resources to function efficiently, it must be possible to purchase a unit of one of the resources conditional on obtaining a certain unit of the other resource. Not only are the resources in general complementary but specific units of the two resources may be complementary.

To achieve static and dynamic efficiency a market system must be characterized by competition in all relevant markets and by the equality of private and social costs and benefits. Furthermore, to be preferred, a market system must achieve a given level of efficiency at lower systems costs.[13]

To fulfill these conditions the markets for space resources should have the following properties: (A) complete allocation regime, (B) divisible and marketable user rights, (C) long contract periods, (D) well-defined liability rules. In the following discussion of these properties it is assumed for each that conditions for efficient markets are fulfilled in all respects other than the issue at hand. In Section III we discuss whether these properties of a

[12] The last aspect of efficiency can also be expressed in terms of static efficiency in the allocation of research and development resources and capital.

[13] This point was emphasized by Coase: ". . . the problem is one of choosing the appropriate social arrangement for dealing with harmful effects. All solutions have costs and there is no reason to suppose that government regulation is called for simply because the problem is not well handled by the market or the firm." Coase, Social Cost, *supra* note 1, at 18. An application of this to the case at hand can be foun A. S. DeVany *et al.*, A Property System for Market Allocation of the Electromagnetic Spectrum: A Legal Economic-Engineering Study, 21 Stan. L. Rev. 1499 (1969).

market system may develop without direction or interference by any authorities. This section assumes that the properties of efficient markets must be deliberately created.

A. *Complete Allocation Regime*

An allocation regime can be efficient only if it includes all resources that substitute for, or complement, each other. Thus, marketable user rights to resources in space must be defined to encompass substitutable modes of producing particular goods and services. For instance, long-distance communications can be transmitted by submarine cable, wire, and wireless as well as by satellite. Since real estate on earth is a well-priced and marketed resource, efficiency requires that scarce orbital positions, too, be priced in competitive markets. This allows a firm to compare the true costs of alternative locations for a relay station. If orbital slots remain free though scarce, too many resources will be invested in the building and launching of satellites.

The allocation of user rights to the electromagnetic spectrum provides another and perhaps a more important example of this principle. The spectrum currently is subject to a dual regime: part is reserved for terrestrial use, part for spatial use. In addition, certain frequency bands are reserved for specific uses. The close substitutability between different parts of the spectrum necessitates that marketable user rights be defined for the entire spectrum—along the ground as well as in space—for the market system to be efficient. Coase's reasoning for the definition of marketable user rights by the Federal Communications Commission for frequency use along the ground applies as well to frequency use on the ground and in space.[14]

B. *Divisible and Marketable User Rights*

The trade-offs facing users of the electromagnetic spectrum are more complicated than a simple choice between ground and space frequencies. Many trade-offs exist with respect to strength of signal, size of antennae, weight of satellites, precision in direction of the signal, and precision in the use of frequencies. Trade-offs occur between different geostationary orbits and other orbits and between the choice of orbit and all of the above aspects of frequency use. The length of time a frequency is used can also be traded off against location aspects and the different aspects of frequency use. The number of combinations among all these variables is immense.

These considerations suggest that the efficient functioning of the market

[14] Coase, FTC, *supra* note 1.

mechanism requires the right to *divide* a purchased user right and to *resell* the whole or a part of it. This requirement is fulfilled for most economic resources but not for space resources. The right to divide and resell parts of the user rights is especially important for achieving efficiency after there has been a change in demand or technology. As the scarcity of the spectrum increases with new uses, divisible user rights would make it possible for the holder of a part of the spectrum to invest in more accurate equipment and to sell off the frequencies that he no longer needs. This would occur if the expected value of the new use exceeds the costs of equipment allowing more precise frequency use.

The same argument can be applied to the area over which a specific frequency spectrum is used. Geographically divisible user rights would allow a holder to sell his right to the frequency in an area if potential new users pay more than the costs of improving the directional qualities of his equipment. Similarly, the wandering of a satellite in geostationary orbit can be reduced by better on-board stabilization equipment (improved station keeping). This allows a larger number of satellites within a limited area without increasing the risk of collision.

C. *Long Contract Periods*

User rights may be purchased for either a limited or an indefinite period of time. While both formally are cases of leasing, a lease for an indefinite period of time in effect conveys a title of ownership to the lessee. How does the length of the contract period affect the efficiency of the market system? We show here that efficiency always prevails with indefinite user rights, while inefficiencies can be caused by time-limited user rights if the duration of the lease is shorter than the economic life span of the satellites. More specifically, it is the time-limit *combined with* costs for transforming the satellite to use by other firms *and* costs for transferring the satellite to other orbit-slots and/or frequencies that cause inefficiency.

For instance, assume that a firm holds the user right to a frequency-location combination for which another firm develops a more profitable use. The latter firm is therefore willing to pay a higher price for the user right than the current holder. If the new firm can use the current satellite more profitably, it could simply purchase the satellite and put it into the more efficient use. If, however, satellites are *firm-specific,* we must distinguish between the case in which the incumbent's equipment is designed for a specific frequency-location combination (factor-specific equipment) and that in which it can be used elsewhere without additional cost (nonfactor-specific equipment).[15]

[15] This distinction may be important at this early stage of space activities. Once launched, satellites cannot easily be moved or changed. Even with space shuttles in use or with more

The case involving nonfactor-specific equipment is the easiest. Efficiency prevails if user rights are defined over limited periods as well as over indefinite periods. A new firm can obtain the frequency and the location simply by paying more for the lease than the current holder is able to extract as rents from a time-limited user right. In the case of indefinite user rights, the new user is willing to pay a higher price than the present value of the holder's rents over time with the inferior equipment or management. By assumption the incumbent can move without any extra costs to another frequency-location combination where its rents on the resources exceed the holder's. Efficiency in the markets for space resources would be restored after a technological change. Efficiency in the third and more general sense also prevails because incentives to develop and invest in new equipment are not hampered by the risk of having to move and change frequency as long as this can be done without any costs.

Partial efficiency in the markets for space resources also prevails in cases involving *factor-specific equipment* with time-limited as well as indefinite user rights. Efficiency with respect to investment and research incentives presumes indefinite rights, however. To show this, consider how efficiency is achieved in the two cases after a technological change. For an *indefinite* user right the new firm must now bid a price that covers the present value of the incumbent's expected rent on the orbit slot and the frequency *plus* compensation to him for capital loss on the equipment. This is efficient because capital destruction should not occur unless new capital is so much more productive that the *increase* in value added covers the expected remaining value added on the old equipment. An identical situation will result with time-limited user rights. It is not sufficient for the new firm simply to bid more for the lease than the current holder pays, because the incumbent will be willing to increase his bid up to the point when he can no longer cover variable costs. The old factor-specific equipment therefore will not be taken out of service until it produces a negative value added at the bid-up price on the user rights. In this situation, the *increase* in value added on the new equipment covers the value added that will no longer be produced with the equipment that is taken out of service.

The above discussion shows that the difference between time-limited and indefinite user rights in the case of factor-specific equipment is that *unanticipated* capital gains or losses are distributed differently. With indefinite user rights the capital gain on the frequency and/or the physical

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well-equipped satellites, the costs of moving, building, and launching satellites must be substantial.

space resource from technological development goes to the incumbent. Thus, he will be able to pay back his initial development costs and investment. However, when the user right is defined over a shorter time period than the expected life span of the equipment, the bid-up leasing costs for the resources after unanticipated technological developments goes to the owner, that is, to the national or international authority that sells user rights. The holder must simply scrap the equipment when he has to pay so much for the lease that his variable costs are not covered. He receives no compensation that can contribute to the covering of the initial investment. Investment risk is higher. Therefore, risk-averse investors will invest less in the development of factor-specific techniques the shorter the time period over which user rights are defined.

One could argue that the price of time-limited user rights will reflect the risk involved in investment in factor-specific equipment so that there will be no effect on investment incentives. That would be the case if *all equipment* were of this type and *all investors* were equally risk-averse. However, it is likely that some kinds of equipment will be factor-specific while others are not. The shorter the duration of the user right, the greater the efforts that would be directed towards developing nonfactor-specific equipment. Indefinite user rights would be neutral in this respect, however, and would not impose any extra costs of developing certain kinds of equipment. Similarly, indefinite user rights would be neutral between more or less risk-averse investors.

D. *Well-Defined Liability Rules*

The previous sections assumed that use of the spectrum is precise with respect to frequency and area affected, and that location of satellites in space is exact. These assumptions, however, are seldom valid. Users of the spectrum interfere with each other and space objects can collide. Thus social and private costs in the uses of the two resources can diverge.

A common regulatory response to such external effects is either to forbid the interference of one activity with others or to put specific technical limits on the external effects. The latter is particularly common in the use of common property resources. Well-known examples are quantitative regulations for air pollution by cars and factories or limits to the amount of waste products discharged in waters. Economists have often argued against specific technological constraints and instead have suggested the taxation of polluting activities.[16] The advantage of this method is that those polluters whose costs of decreasing their pollution are lowest will do so first. The desired level of pollution is thus obtained at least cost.

[16] A. C. Pigou, The Economics of Welfare 183 (1932).

Coase has argued that the so-called Pigovian approach is often inefficient.[17] It may cost less for the activity harmed by pollution to reallocate or to protect itself than for the polluter to reallocate or decrease its emissions. Furthermore, Coase argued, an efficient allocation of resources could come about via market-induced negotiations without any intervention from regulatory agencies. Which system of reducing external effects is more efficient depends on information, transactions, negotiations, and enforcement costs—that is, on systems costs.

The electromagnetic spectrum and the physical space resource present similar problems of external effects in production. Use of the spectrum may involve interference, but the optimal degree of interference may not be zero. Nor is interference necessarily reduced most cheaply by requiring the source of the interference to adjust its activity level. Similarly, use of physical space involves a risk of collision, but the optimal probability of collision is not necessarily zero.[18]

We contend that most external effects in the uses of space resource can be reduced to efficient levels by market-induced negotiations once liability rules are defined and enforced. This is superior to a system of Pigovian taxes because most interferences in the uses of space resources occur between very few parties at adjoining frequencies or orbit slots. The external effects are then relatively "individualized" so that the costs of finding negotiating parties become relatively low for space resources. The Pigovian solution is superior on the other hand when external effects are "generalized," and many parties are affected by a particular activity so that the costs of starting and conducting negotiations are relatively high. But a tax can be inefficient, for instance, if it forces a polluter to adjust even when those activities hurt by pollution could adjust at lower costs; additionally, a tax cannot be fine-tuned to every different kind of pollution or interference in different areas.

By way of illustration, consider a firm that has obtained the user rights for a frequency and an orbit slot. The firm plans to launch a satellite and must decide on a number of variables, such as exact specifications on antennae, ability to direct the signal, ability to remit with little interference on adjoining frequencies, the size of the area within which the satellite wanders, and the strength of signals. We have previously considered some trade-offs between these variables; here we consider the additional trade-offs between equipment costs and the costs of interfering in different respects with other users of the spectrum and of space.

[17] Coase, Social Cost, *supra* note 1.

[18] The physical use of space may also involve shadowing. Large space objects can temporarily shadow others and therefore cut off their energy supply. The economic problem in this case is perfectly analogous to the ones discussed in the text.

It follows from Coase's argument that an optimal degree of interference and collision risk can be brought about, whether or not a liability rule is defined, if no costs are involved in identifying potential sources of interference for uses of adjoining resources, in setting up negotiations, in conducting negotiations, and in enforcing an agreement.[19] The definition of a liability rule will determine who bears the costs of adjusting to interferences; it will not affect the level of interference.[20]

The optimal degree of interference would be reached even when current holders and new entrants interfere with one another. All parties would gain by negotiating mutual improvements in equipment until the costs of improvements exceed the gains.

The assumptions under which this market solution would be reached are very restrictive, however. For instance, the users of adjoining frequencies and locations are assumed to know the degree of interference that will be caused by the new entrant. When this information is lacking, a liability rule is necessary or newcomers could benefit by installing low-quality, interfering equipment that is very expensive to modify once it is in use. Measures to decrease interference are likely to be much cheaper if they are implemented before the space objects are installed. Current users of adjoining frequencies and locations must pay a higher price, therefore, to reduce interference to an optimal level (as defined in the case with perfect information). If instead the new entrant were liable for damages caused by his satellite, he would be induced to start negotiations when the costs of modifying the equipment are at a minimum.

The situation is more complicated when the number of parties with economic interests increases, that is, when interference is "generalized" and when starting negotiations, negotiating, and enforcing agreements all become more costly. A new entrant may be unable to obtain information on every party with which he may potentially interfere. Such situations could occur for airplane-to-ground communications, broadcasting from satellite over wide areas to household receivers, navigation satellites, and so on. It would then be cheaper for an authority to specify the quality of

[19] "In order to carry out a market transaction it is necessary to discover who it is one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to a bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on." Coase, Social Cost, *supra* note 1, at 15.

[20] We do not discuss how a liability rule should be defined but assume that it can be defined in such a way that the marginal cost curve of the damaged party is restored as if no external economies existed. There are great problems in defining such a liability rule, however. See, for example, Michelle White, Long-Run versus Short-Run Remedies for Spatial Externalities: Liability Rules, Pollution Taxes, and Zoning (1979) (unpublished paper at New York University).

equipment or to assign a tax per unit of interference. The administrative costs of such solutions must be weighed against the potential gains.

Liability rules are clearly not sufficient for social efficiency in all uses of space resources. However, the "generalized" cases of interference may be the exceptions rather than the rule. Cases of widespread interference can be investigated to determine whether they in fact are efficient or whether a tax could be applied at lower systems costs than a market solution with liability rules.

An additional advantage of initially creating an institutional framework for the market solution, rather than relying on a bureaucratic system, is that the burden of proving inefficiencies then lies with those who advocate direct regulatory allocation measures. We know that the market tends towards efficiency, and we know the conditions under which bureaucratic procedures can alleviate remaining inefficiencies. These conditions can be investigated for specific cases. The opposite strategy, the creation of a centralized agency for the allocation of space resources, does not inherently tend towards efficiency. A decision to start with a regulatory solution would put the burden of proving inefficiencies in the system on those advocating a market solution. As no one case of inefficiency can be remedied by a market process without *all* potential users being subject to the market test, it would, in fact, be impossible for any particular user to show that the market solution would be better. Thus, a market process would be more flexible in that it could be supplemented by regulatory measures when needed, while flexibility in the opposite direction does not accompany the bureaucratic system.

The advantages of allocating user rights by markets rather than by the current regulatory system are particularly striking when we consider the many dimensions of the orbit-frequency resource and the possible trade-offs between them. The amount of information needed to allocate the spectrum and orbit positions efficiently is enormous. This information is widely dispersed among many producers and consumers and is not available to a regulatory agency. The market mechanism has the unique ability to allocate resources despite the wide dispersion of information.[21]

This is the implicit conclusion of a U.S. position paper for the 1979 World Administrative Radio Conference. After stating that "a quantitative approach to the problem of choosing criteria for measuring efficiency is desirable" the report recognizes the complexity of the problem and concludes that

[21] See, for examj F. A. Hayek, The Pretence of Knowledge, 77 Swedish J. Econ. 433 (1975), for elaboration on this point in a general framework. See also Adam Smith, The Wealth of Nations (1776).

when determining orbit-spectrum efficiency, recognition must be given to user's requirements, that is, efficiency must be treated as a relative parameter vis-à-vis the various communication services, with efforts made to optimize efficiency within a given service.[22]

The impossibility of a quantitative approach in choosing efficiency criteria should not surprise the economist. Efficient use of a resource is an economic concept that lends itself poorly to technological measurements.

This section concludes that efficiency requires the definition of (*a*) complete markets for indefinite and divisible user rights to the two space resources, (*b*) liability rules for interference when users of space resources lack information about the technology of potential users, and the use of (*c*) taxation or possibly direct regulation of activities for which the identification of damages and the enforcement of liability rules are relatively costly.

III. Choice of Management Regime: Efficiency and Equity Considerations

Is there any need for an international orbit and frequency authority, and, if so, what roles should such an authority have? This section concludes that an authority can contribute little to achieving *efficiency* once the institutional framework for complete markets exist. However, well-functioning international markets may require international trade and legal conventions. The main task of an international space resource authority is instead to achieve *equity* in the distribution of rents among nations. We suggest, therefore, creating an international condominium to auction the electromagnetic spectrum and the orbits and to distribute the resulting revenues.

The current regime has been called a squatters'-rights regime because ownership is distributed on a first-come, first-served basis. This is a misnomer in one important respect. Once a squatter's claim is secured, his property rights are complete and he can sell his farm to more efficient, more eager farmers or subdivide it for development. This was the case on the American frontier during the 1800s.[23] While it is true that a user of

[22] U.S. Dep't of State, Considerations in the Matter of Measures of Geostationary Orbit-Spectrum Efficiency for the Mobile Satellite Service 1 (CCIR Study Groups, Special Preparatory Meeting, WARC-79) (Doc. P/226-E 20, June 1978).

[23] In the settlement of plentiful land in the United States, pioneers had the right to cultivate uncultivated land and to claim ownership of the developed land after a specific interval had passed without anyone else substantiating claims to the same piece of land. The squatter's ownership rights, once established, were not limited. He could resell or subdivide the land.

orbit slots or the frequency spectrum is a squatter in the sense of claiming resources not used by anyone else, his claim and use of these resources do not grant him the right to sell all or part of them. His property rights are therefore circumscribed in an important respect which distinguishes the current regime from a true squatter's regime. Currently there are restrictions on the intranational transfer of user rights as well on their international trading. For example, the Federal Communications Commission must approve users of the electromagnetic spectrum in the United States.

A true squatters'-rights regime may be less efficient than auctioning user rights even when the conditions for efficient markets are fulfilled. One reason is that transfer costs between different orbits and frequencies may prevent a latecomer in space from obtaining an optimal position or frequency, since the resources cannot be claimed without physical presence. The complementary nature of orbit slots and frequencies emphasizes this inefficiency of the squatters'-rights regime because a potential user of space resources cannot claim parts of the two resources simultaneously. An auctioning system could be designed in such a way that this complementarity could be recognized, however. A second inefficiency inherent in squatters' rights, at least at an initial stage, could arise when the income-constrained prices that firms are willing to pay for the resources are lower than the prices that the same firms demand to give up the resources.[24] An auction of space resources at a very early stage in the exploitation of space could decrease this problem initially. However, the major difference between a squatters'-rights regime and a resource auction is related to the problem of equity rather than efficiency. We shall return to this issue below.

Our conditions for efficiency above include freedom of international as well as intranational trade. Inefficiencies arise if governments restrict bidding for their share of the resources to domestic firms. Only by chance would domestic and foreign prices be equal in a no-trade situation. Tariffs or quotas on trade in space resources therefore entail global welfare losses, and a convention on international free trade in user rights is necessary for efficiency. Thus, there is an important role for international conventions similar to those of the General Agreement on Tariffs and Trade (GATT). The optimal tariff argument suggests that one country could gain by restricting trade in its shares of the space resources if these were imperfect substitutes for the shares of other countries and possessed a comparative advantage in producing specific services demanded by other nations. Therefore, in an initial distribution of property rights no single

[24] See A. C. Fisher & J. V. Krutilla, Managing the Public Lands: Assignment of Property Rights and Valuation of Resources, in The Governance of Common Property Resources (Edwin T. Haeffele ed. 1974).

country or small group of countries should be given a monopoly on specific space resources that it can exploit by imposing an optimal tariff.

Some nations may also wish to allocate all or parts of their resources in a bureaucratic manner. For example, nations may reserve parts of the spectrum for military purposes or for other services that are supplied by government authorities. The frequency spectrum can provide public goods, such as emergency communications and military services, which are nonmarketable, but this should not free the respective government authority from the market test of the willingness to pay for the use of a scarce resource.

Once parts of the resource are allocated by nonmarket methods, it is impossible to say whether the market mechanism would lead to the optimal allocation of remaining parts. We face a second-best problem. However, we cannot argue that any other mechanism would function better in general. What we can say is that the market mechanism would lead to an efficient allocation of the remaining marketable space resources if there were little substitutability between those resources allocated bureaucratically and those allocated through a market. This is likely to be the case for many uses of space resources in providing services on a national level. It may not be the case, however, for services provided both by frequency use in space and along the ground. The gratis resource would be overutilized relative to the marketed part of the spectrum.

Inevitable interferences in the use of spectrum and orbit resources suggest the need for an international legal convention, because liability rules must be defined and enforced. Such a convention would not be necessary if enough national laws were directly applicable to the use of space resources. Lacking these, international interference requires an international legal framework that is accepted and enforced by all nations. Specification of such a legal framework would not be unique. Parallels exist in international law, such as the liability rules regulating collision at sea. Liability rules could either be accepted internationally and enforced by courts in individual nations, or the international authority could serve as a court for cases involving damages in the use of the frequency spectrum and the physical space resource.

The need for taxation or direct regulation of the use of the spectrum and the orbit resources by an international authority arises only when so many activities are affected by some particular activity that liability rules are not sufficient to reduce interference to an optimal level. It then becomes too costly to negotiate with all parties involved and to enforce liability rules through court procedures. Frequencies for emergency signaling at sea, maritime communication and navigation satellites, and air-transport communications are examples of such activities. A worldwide assignment

of certain frequencies to these activities and specification of signal strength and other characteristics may be the system that offers the lowest social costs.

The major task of an international authority for managing space resources will be to distribute rents. When a nonreproducible resource becomes scarce, it generates rents. Discussion of the normative questions of who should enjoy these rents and how the desired distribution can be achieved has often been confused since space has traditionally been considered an international common property resource to which access is open and free. Property rights to the resource consequently have usually not been precisely defined and their rents have seldom appeared explicitly.[25] The importance of rents is nevertheless illustrated by the struggle over property rights at the World Administrative Radio Conference (WARC-79) proceedings.

Allocating user rights through a regime of squatters' rights would resemble the acquisition of titles to gold and land during the westward push of the American frontier. Space would be a new frontier and firms and nations would rush to claim the most valuable orbit slots and frequencies. The best-equipped firms in the most technologically advanced nations could quickly claim valuable space property, and little of the rents would remain for other nations. Such a regime is unacceptable to most countries.[26]

The current regime regulating access to the electromagnetic spectrum and orbits is similar to that traditionally used for commons. Governments apply for user rights to the International Telecommunications Union which grants such rights on a first-come, first-served basis for an unlimited time period. The applicant is in effect granted rents for the period of use.[27] If entry were not regulated by this nonmarket method, rents would be dissipated through congestion and interference.[28]

Some developing countries have proposed either that user rights be reserved for future use by countries that have no current use for them or that the electromagnetic spectrum and the satellite orbit be subdivided

[25] The common statement that common property resources belong to everyone and therefore to no one reflects this lack of precision. It contains a non sequitur which may be responsible for some of the confusion.

[26] The equatorial countries have claimed sovereignty over the part of the geostationary orbit which is immediately above their territory. These claims have not been recognized by others.

[27] In general, the rents may appear in any monopolized stage of the production process for final services. For example, if an equatorial country holds a monopoly on advantageous launching sites, it can extract space rents by imposing launching fees.

[28] Dissipation of rents is a well-known phenomenon in the fishing industry with unregulated and gratis entry.

and title to its parts distributed among countries in an equitable manner. These two procedures are equivalent in terms of equity when user rights are accorded in perpetuity. However, unless markets for resale or subleasing of space resources are also allowed, greater equity is achieved at the expense of less efficiency since scarce resources will be hoarded for future use.

The auction method for allocating user rights as a way to ensure efficiency in resource use is consistent with any distribution of rents. The equity aspect of managing orbits and frequencies could therefore be separated from efficiency aspects. This separation would be complete with perfect capital markets and speculative investors linking current and expected future prices. An International Space Condominium could be set up to manage the electromagnetic spectrum and satellite orbits. The condominium could lease or sell the rights to use these resources for limited or unlimited periods of time to the highest bidder. If bidding is competitive, auctioning user rights would maximize the rents due to the scarce resource. Revenues, net of operating expenses, could be distributed to the shareholders, which initially might be national governments. The distribution of rents would then be determined by how shares in the condominium are distributed among governments.[29]

This regime for international communal ownership has several advantages over the current system:

1. The resources are put to most efficient use and rents are maximized when rights to use them are auctioned to the most efficient users. The auctioning system is, furthermore, an impartial method of allocation.
2. The distribution of rents can be designed to conform to what the international community considers an equitable distribution; this can be done through international negotiations to determine the initial distribution of shares in the condominium.
3. The allocation of user rights is separated from the distribution of rents and the question of efficiency is thereby separated from the question of equity. Only the distributive aspects are subject to political negotiations.

The advantages of the proposed condominium over the existing proposal to carve up and nationalize the electromagnetic spectrum and orbit slots are not as clear. Carving up resources among nations may, in principle, be as efficient as an auction system if it is combined with international

[29] We do not treat the interesting question whether governments should be allowed to sell their shares to other governments or to private entities. Should the shares resemble SDRs or freely transferable assets?

free trade and with appropriate legal conventions. Also the resources, in principle, could be carved up and distributed in such proportions that they would provide the desired distribution of rents. In respect to efficiency and equity, the two proposals are equivalent. However, certain practical and additional considerations make our proposal superior to nationalization.

First, the strength of national vested interests suggests that the initial distribution of titles to space resources will more or less reflect the existing distribution of user rights. It may be politically difficult to award title to frequency bands to countries other than those that currently have user rights to them. It may also be costly if the new distribution of ownership rights causes a redistribution of user rights because of a reluctance on the part of countries to trade in user rights. A more substantial redistribution of wealth in favor of the poorer countries may therefore be achieved if existing user rights were left intact and thereafter acquired—or lost—in the marketplace. The resulting rental income would instead be distributed at the political negotiating table.

Second, while it is possible to subdivide space resources and distribute titles to the parts, it is impossible to achieve a desired distribution with a reasonable degree of accuracy. Frequency bands and orbital positions are heterogeneous factors of production. Without markets where they can be traded, their value cannot be accurately established. In short, the value of the resources being distributed is unknown. Lacking this information, a lottery of frequency bands and orbital positions could probably achieve the desired distribution of wealth as well as a planned distribution. Large rich countries with diversified economies and a preference for risk should find a space-asset lottery less objectionable than would small developing countries. Yet the latter have advanced the proposal for carving up the common property. While they may prefer this to the existing regime, we believe it is inferior to the proposed condominium regime. Owning a share in a portfolio of diverse space assets is less risky than owning a single space asset.

Finally, search and administrative costs in the markets for orbits and frequencies could be minimized when transactions are made via the international condominium, which would serve as an exchange.

IV. Summary and Conclusions

We have suggested a regime for managing the two space resources, the physical space resource and the electromagnetic spectrum. To achieve efficiency an international convention establishing intra- and international free trade in divisible, indefinite user rights to the complete resources

should be agreed upon. A legal convention on the definition and enforcement of liability rules is also crucial for efficiency. An authority to manage space resources is needed only for those activities that interfere with a large number of other activities.

To achieve equity, we have suggested the creation of an international space condominium to auction user rights to the two resources. The rents from the scarce resources would be distributed in proportion to nations' shares in it. The distribution of these shares would be determined by political negotiations. One advantage of this proposal over the current regime and other proposals is that the political struggle for rents would not interfere with efficiency in the use of resources. The condominium could auction limited user rights at recurrent intervals or it could be dissolved after it had distributed the rents from its first—and last—auction of unlimited user rights. An international management authority could remain to oversee international conventions and directly regulated activities. A regime of unlimited user rights to the resources may be politically unacceptable because unanticipated capital gains accrue to individual holders rather than to the international community. Leasing of user rights for specific time periods by the condominium may result in a more acceptable distribution of these capital gains—and losses—but involves some loss of efficiency.