Reallocation of Radiowave Spectrum with a Price Mechanism: Proposal of a System of Insurance and Compensation[1]

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I. Introduction and Background

A. Outline of the paper

The use of radiowave spectrum is managed in two steps: allocation and assignment. Allocation specifies for what purposes a band of spectrum is used, and assignment specifies who is entitled to use each block of a spectrum band. For efficient use of spectrum, it is necessary to adjust allocation and assignment from time to time, since new technology emerges one after another and the demand for spectrum changes continuously. Yet, because of vested interests of incumbent users, it is difficult to do this under command and control by a national government or through negotiations in ITU.

The objective of this paper is to propose a mechanism for adjusting allocation, as distinct from assignment, by means of insurance, compensation, and supply-price revelation; in short, it is a price mechanism for spectrum reallocation. The mechanism can reallocate spectrum in such a way that the band currently used with the lowest efficiency is released for a new use with higher efficiency; the users of the reallocated band are compensated properly.

The following summarizes the way in which the proposed mechanism works. (1) Each spectrum user declares an amount of compensation to be paid in case of reallocation. (2) Each user pays a compensation premium to the government which is equal to the declared compensation multiplied by the premium rate. (3) The government determines the size of spectrum bands to be reallocated. (4) The actual spectrum bands to be reallocated are chosen so as to minimize the total amount of compensations with consideration of externalities in using spectrum. (5) The government sets the premium rate so as to balance the total premiums collected from all users and the total compensations paid in the long run. Thus, the mechanism is a fair insurance on reallocation except that, in ordinary insurance, casualty takes place randomly, while, in this mechanism, “casualty” is a consequence of government decision. The mechanism can prevent “spectrum hold-up,” since each spectrum user has an incentive to reveal the cost of reallocation as an amount of compensation truthfully. The balanced-revenue-expenditure requirement implies that the cost of reallocation is distributed among all spectrum users; this is desirable, since reallocation forces a few users to exit in order to solve the shortage of spectrum for which all users, not those forced to exit, are responsible.

The proposed mechanism can work with various assignment systems. With market-oriented systems such as private property and competitive lease, it will work nicely. When the mechanism

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is implemented with command-and-control assignment, there is possibility that the user of a reallocated band is assigned with a block in another band as partial compensation. Such a case can still be managed by introducing conditional compensations. When a spectrum band is used under commons mode, each user declares an amount of compensation; the government calculates the total compensations by summing up all the declared amounts. The paper proposes a way in which end users (consumers) are compensated when spectrum-dependent services (such as mobile telephony) are terminated because of reallocation.

The paper considers a way to extend the proposed mechanism to international spectrum allocation. When a member country allocates spectrum domestically according to the mechanism, it is straightforward to put the preference of the domestic users through to ITU. Otherwise, the government will have to act as an agent representing to ITU the preference of its spectrum users.

B. Radiowave resources

In this paper, we consider *radiowave spectrum* as an economic resource. Radiowave spectrum covers the electro-magnetic waves of which the frequency ranges from 3KHz to 300GHz. Radiowave spectrum is used widely for communication and other purposes. Because of the advancement of wireless technology during recent years, the use of radiowave spectrum has become indispensable in our daily life and business.

Let us first summarize the properties of radiowave spectrum viewed as an economic resource. First of all, spectrum is a non-reproducible natural resource. It is different from oil or mineral deposits in that it does not deplete. It is different from produced capital like machines and equipment in that it does not depreciate. Radio spectrum, however, is not a resource of unlimited supply.

In order to understand the supply, or in general the quantity, of spectrum, it is useful to consider its resemblance to *land* as a resource. Land is a non-reproducible, non-depletable natural resource with limited supply; in addition, a piece of land has boundaries and a size. In fact, both land and spectrum as economic resources can be grouped into a category of *space resources*, of which examples are land space, water space, air space, the space of satellite orbits, to name a few. The resemblance of radiowave spectrum to land is a consequence of the fact that the utility of land arises from using a portion of the surface of the earth physically, whereas the utility of spectrum arises from using a portion of the surface of the earth electro-magnetically (terrestrial spectrum), or from using a portion of the geo-stationary satellite orbit electro-magnetically (satellite spectrum). Thus, the term “spectrum” means, in many cases, not electro-magnetic waves themselves, but a space for electro-magnetic waves to propagate through.[2]

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[2] In general, we attach dimension to a space, which is the number of independent axes, and a measure to represent the size of a portion of the space. Physical spaces such as land space or water-surface space have two dimensions and air space three dimensions. The satellite orbit is a one-dimensional space. Terrestrial spectrum spaces may be considered to be of three dimensions, since, to the two dimensions for designating an area on the earth, we add one more dimension for radio frequencies. Likewise, satellite spectrum spaces have two dimensions for communicating at a point on the earth (one from the satellite orbit and one from frequencies), and four dimensions for communicating from any point on the surface of the earth (two more dimensions added to designate an area of the earth).

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In order to utilize spectrum, we need to rely on some technology. In fact, for almost all cases, we need to use devices such as a receiver and a transmitter in wireless communication. Observe that the use of land also depends on technology, and, of course, we need to use some means such as buildings or transportation equipment to derive utility from land. In short, we need some capital stock for using a space resource, be it land or spectrum.

Technological progress enables us to utilize land or spectrum more efficiently; examples are skyscrapers or multi-lane highways for using land and technologies developed recently for using a given spectrum more efficiently such as spread spectrum, software radios, and UWB.

Further, externality is a property commonly observed in using land or spectrum as an economic resource. Land exhibits positive externalities in the form of economies of scale area-wise, and similarly spectrum exhibits positive externalities frequency-wise as well as area-wise. Further, both have negative externalities arising from excessive use of a space; they are called congestions for land or interferences for spectrum.

C. History

The invention of wireless technology was accomplished toward the end of the nineteenth century. In the beginning of the twentieth century, spectrum was used for navigational safety and navy operations. Ever since that time, the utilization of spectrum has expanded steadily. In the 1920s, voice radio became popular, and in the 1940s, during the war, radar was invented. Since the 1950s, television receivers have become a major household good. Today, in many countries, mobile telephony shows penetration far exceeding one-half of the population and spectrum is used widely for many other purposes.

Such remarkable development of the utilization of radio spectrum was accomplished, needless to say, by a succession of technological advances. Typically, a new technology was invented by making use of a new band of radio frequencies which had so far been unused. Thus, the development of wireless technology was an expansion of the frequency-frontier of spectrum utilization. The issue to be dealt with in this paper arises from the fact that this frontier has nearly been exhausted. To be more precise, we should say that there remain many bands unused or rarely used in high frequencies such as in micro-wave bands. However, with today's technology, these high-frequency bands are not so easily or economically usable. In comparison with this, spectrum bands of medium frequencies such as those below 3GHz (including VHF and UHF) are quite useful to us and the demand for these frequencies exceeds the supply, especially in urban areas. As a consequence, the right to use spectrum in VHF or UHF bands in urban areas carries a high economic value now.

D. Management of spectrum

The utilization of radio spectrum at the present time is administered in two stages; the first stage is *allocation* of spectrum *bands* for specific *objectives* and the second stage is assignment of spectrum blocks to users. Allocation of spectrum is done in two levels, international and national. International allocation of spectrum is conducted by the International Telecommunication Union (ITU) and by other international bodies. At this level, overall allocation of spectrum bands is agreed upon by member countries; a recent example of such agreement made by ITU is the

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specification of a certain band in UHF for the use of RFID.

The national level of spectrum allocation is made by national government, which specifies one or more objectives for using a spectrum band in more detail together with technological specifications including the power of radio emissions, the allowance of interferences, and the format of modulation and coding needed for information transmission.

The need for spectrum allocation arises from the presence of positive and negative externalities in using spectrum. It resembles to “zoning” in city planning for using land spaces. If there were no externalities in using spectrum, there would be no need for ITU or national government to allocate it. It is noted that, in general, technological advances contribute to promoting the benefits from positive externalities and to preventing the harms from negative externalities. Thus, the need for spectrum allocation is expected to vary (usually decrease) with technological advances.

The second stage of managing spectrum resources is *assignment* of a spectrum *block* to users. Typically, a spectrum band is divided into a number of spectrum blocks, frequency-wise and area-wise, to each of which a single user or multiple users are assigned with or without a license. An assignment also specifies the time (of a day, a week, etc.) in which spectrum is used together with technological specifications.

Historically, the main objective of allocation and assignment was to prevent interferences among spectrum users, and also to promote efficient utilization of spectrum in consideration of positive externalities. During the time in which wireless technology was advancing ahead of spectrum needs, the task of allocation and assignment was easy, since the supply of spectrum exceeded the demand. Once spectrum shortage emerged, however, the situation changed enormously; ITU and the national government must now solve a difficult problem how to satisfy the demand for spectrum resources which exceed the given supply. The subject to be dealt with in this paper has become important because of this.

E. Modes and institutions for spectrum management

In this subsection, we consider various *modes* and *institutions* for managing spectrum resources. Much has been debated on this subject during recent years.[3] The objective of this subsection is to give a summary for the discussion in this paper.

The first mode for spectrum utilization is the *exclusive use*, in which a spectrum block is assigned exclusively to a single user with a license. For exclusive utilization of spectrum, we distinguish two institutions; the first is command and control and the second is market mechanism.

Command and control is the traditional system of spectrum management having been adopted in many countries. After a spectrum block is established with specifications regarding a frequency range, an area for use, and the emission power and other technical specifications, the user of a block is selected according to the first-come basis, random selection (lottery), or comparative hearings (beauty contest). The license for using a block is of a limited period of time, but usually it is

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[3] See, e.g., Faulhaber and Farker [2002], FCC [2002], GAO [2003], and Hazlett[1998].

renewable. Typically, there are no rental or lease payments imposed on users except that nominal fees may be charged by the national government for the cost of document processing, database maintenance, and policing to prevent interferences.

The second of the two institutions for spectrum assignment is *market mechanism*, in which the law of demand and supply with prices functions to control the right to use a block. In one system, spectrum is treated as a *private property* in the same way as land is in many countries. In this system, auction may be used for initial assignment of spectrum and market transaction of the right to use a block is allowed. As a consequence, secondary property markets and also secondary lease markets for spectrum may emerge.

The other system of market mechanism for assigning spectrum blocks is the *competitive lease and renewal* by national government. In this system, the national government remains to be the owner of the spectrum resources and leases spectrum blocks competitively to users. Lease prices may be determined by an auction; in this case the government needs to consider some way to protect incumbent users at renewal auctions[4]. Further, secondary markets may develop for transacting the right to use a spectrum block.

In comparing market mechanism with command and control as a means to assign a spectrum block, it is agreed upon widely that market mechanism is better than command and control in promoting efficient utilization of spectrum resources.

The second category of the modes for using spectrum blocks includes *club* and *commons*. In both of these, multiple users are assigned to a single block. The difference between a club and commons lies in the degree of freedom for new entry. In the club use, new entry is unrestricted or restricted by the government. It is customary that a license is issued to club users. Typical examples are amateur wireless communication and wireless communications used for the safety in navigation or aviation. To avoid interferences, a club user begins using a communication channel only when the channel is not used by others. For this reason, we may characterize a club use to be a time-shared exclusive use.

A spectrum block for commons is opened to the public for free use under technical restrictions such as very weak power emission. Interferences between users are avoided, if not completely, as a consequence of these technical restrictions. No license is required in commons (hence, *unlicensed band*). Typical examples of commons are the ISM band and the bands for wireless LAN, wireless Internet access, and RFID.

Club and commons can be realized under command and control or under market mechanism. A typical case at the present time is the one under command and control, in which ITU and national government designate a block to be of club or commons use; no fee is charged from users. A club or commons under market mechanism may be supplied by a public agent. Such an agent would represent the aggregate interest of the users of the block; the agent would first secure the right to use it exclusively in the spectrum market and would then offer it as a club or commons. The cost needed for the agent to secure the block would have to be paid collectively from the general budget

[4] For details, see Oniki [2002].

of the government.[5]

Roughly speaking, there are two arguments around the choice of a mode and of an institution for spectrum assignment. One argument recommends to introduce market mechanism for the reason that it can promote efficient use of spectrum resources[6]. The other argument insists introduction of commons by emphasizing the advantage of spectrum sharing accomplished by recent technological progress.[7] Observe that the two arguments are not mutually exclusive; in fact, it is possible to let an assignment under market mechanism and an assignment with commons coexist side by side and compete each other, provided that spectrum bands can be supplied for these uses[8]. The problem lies in the shortage of spectrum bands which can be allocated to new uses under market mechanism or with commons.

As stated previously, allocation of new spectrum bands and reallocation of spectrum bands in use is the responsibility of an international organization such as ITU worldwide, and of national government within the national border. Because of shortage, new allocation of useful spectrum bands such as VHF and UHF has become almost impossible today. Reallocation of useful spectrum bands currently in use is more difficult than new allocation.

In ITU, interests of member countries are in conflict; it takes a long time for member countries to reach an agreement on reallocating spectrum bands even for a strongly needed objective such as wireless LAN, wireless Internet access, or RFID. The situation is the same in domestic reallocation. National government, under command and control, attempts to reallocate spectrum bands from incumbent users to new users who can use them more efficiently. Needless to say, objections from incumbent users are so strong that it takes a long time for the national government to accomplish reallocating useful spectrum bands.[9] Thus, it remains only a dream to open up useful spectrum bands for inviting new inventions yet to be accomplished.

The objective of this paper is to propose a system by means of which such difficulty in reallocating useful spectrum bands may be overcome by utilizing the power of price mechanism combined with insurance and compensation.

II. Reallocation of Spectrum with Insurance and Compensation (RIC)

A. Outline

This section gives an outline of the system for reallocating spectrum bands with insurance and compensation, which will be written as *RIC* in this paper. In short, it is a system by means of which the supply price of spectrum bands is revealed for reallocation by incumbent users through a

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[5] Ibid.
[6] See, e.g., Coase[1959], Cave[2002], FCC-SPTF[2002], Hazlett[1998], and Kwerel and Williams[2002].
[7] See, e.g., Benkler [2002] and Ikeda and Ye[2003]. See also Faulhaber ad Farber[2002], and FCC-SPTF[2002].
[8] See Benker [2002], Section VII.
[9] In Japan, there has been only a few cases in which useful spectrum bands were reallocated successfully since 1980s; the average time period needed for a case of reallocation was ten years or so. For a discussion of the difficulty of spectrum reallocation (relocation), see Cramton [1998].

mechanism of insurance and compensation.[10] Figures 1(a) and (b) illustrate the activities in RIC.

First of all, to incumbent spectrum users, the system RIC is a mandatory insurance with compensation. Thus, each spectrum user (including government and other public users) declares a monetary amount of *compensation* to be paid to the user by the government in the event that the spectrum block being used by the user is reclaimed and becomes unusable. Each spectrum user pays an insurance premium (*compensation premium*) to the government annually, which is equal to the amount of compensation multiplied by the *rate of compensation premium* to be determined by the government. Thus,

(compensation premium)

= (compensation premium rate) * (compensation amount declared).

To spectrum users, the system is nothing but a casualty insurance plan, where a casualty here is the event that the spectrum block becomes unusable.

In this system, the government plays the role of an insurance company. First, the government determines the rate of compensation premium. The principle that the government follows in doing this is the long-run balance of the RIC budget; the rate of compensation premium is chosen so as to balance the income from premiums paid by the spectrum users and the outlays paid by the government for compensating those users with spectrum blocks reclaimed.[11]

Each year, the government selects spectrum bands to be reallocated; we will discuss in the following and later subsections on what criteria the government should do this. The government pays compensations to users whose blocks are reclaimed.

B. Selection of spectrum bands to be reallocated

In RIC, selection of spectrum bands to be reallocated is done by the government in two steps as described below. The first is to identify a new objective of using spectrum bands. This decision depends on the speed of technological development and other factors such as the demand for spectrum with a new objective and the state of standard formation. After a new objective is established, the government determines the size of spectrum bands to be allocated for the new use. This decision may be done with governmental discretions if the assignment is under command and control, or by using price data expressing the value of spectrum bands if the assignment is made with market mechanism.

The second step of reallocation is to designate spectrum bands to be reclaimed from current use and to be reallocated for the new use. If reallocation is conducted under command and control, as stated previously, this is an extremely difficult decision to the government. Under RIC, however, this decision would be easier. The government should choose spectrum bands to be reclaimed so as

[10] Ikeda and Ye [2003] proposed a system of “reverse auction” for spectrum reallocation, in which the supply price of spectrum is revealed by incumbent users who attempt to “sell” the right to use spectrum to the government at a price as high as possible. Their system, however, does not have a provision of insurance and compensation.
[11] See II.C below for details.

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to minimize the total amount of compensations to be paid for the reallocation. In doing this, however, the government needs to take into account the presence of positive externalities. Typically, it is desirable to reclaim spectrum bands which are contiguous, or at least located nearby, frequency-wise. Thus the selection of spectrum bands to be reclaimed may not be as simple as minimization of the compensation outlays. It is clear, however, that selection of spectrum bands to be reclaimed with RIC is far easier and less disputable than that under command and control. We will discuss these points more in detail in Section IV.

C. Determination of the rate of compensation premiums

The rate of compensation premiums is to be determined by the government. It is best for the government to adjust the rate in such a way that the *long-run* balance between the premium income to the government and the compensation outlays paid to users whose spectrum is reclaimed. In other words, the RIC budget should be run by the government so as not to produce any surplus or loss in the long run. A reason such long-run balance is desirable is that it keeps the activities related to spectrum reallocation neutral to the activities in other sectors of the society. Another reason is discussed in the following subsection.

It is noted that, when RIC is actually implemented, the total amount of money paid by the government for compensation will change from year to year. In some year, there may be a major reallocation of spectrum bands; the compensation outlays will be high in that year. It is possible that, for some years following the year of a major reallocation, there is little or no reallocation. In such a case, if the annual premium rate is determined so as to balance the *annual* income and outlays of the RIC budget, the rate will fluctuate sharply over years. It is desirable to let users avoid from facing such fluctuating rates. One reason is to decrease uncertainty to spectrum users. Another reason is not to give users an incentive to speculate on an amount of compensation declared.

Thus, the objective for the government to set a premium rate should be the long-run balance of the RIC budget, as distinct from its short-run balance. A way to do this is to adjust the premium rate with lags toward balancing the RIC budget, avoiding drastic changes, even after a major reallocation. The RIC budget in such a case may exhibit deficits for some years, which may be financed commercially. Such a gradual adjustment of the premium rate may be done with governmental discretions, or by following a pre-determined algorithm (adjustment rules); designing such an algorithm is left for future research.

D. **Implications of RIC as an insurance**

The long-run balance of the RIC budget implies that, under certain conditions, RIC becomes what is called *fair insurance* in economic theory. We consider the following situation. Suppose that the probability in which spectrum is reallocated is considered to be equal over all spectrum users and over all spectrum bands. Then, we can state that the probability of spectrum reallocation to users is equal to the average premium rate in the long run.

It is known that, in such a case, a rational spectrum user maximizing the expected utility will choose what is called a complete insurance plan, in which the level of utility in the case of spectrum

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reallocation is equal to the level of utility in the case of no reallocation.[12] In other words, with a complete insurance plan, there is no room for users to improve the level of utility regardless whether or not a casualty occurs.

Of course, in reality, the assumptions stated above will not be satisfied. After all, a casualty in RIC is not an event such as fire or flood, which is not controllable, but a consequence of a government decision to reallocate spectrum bands. The discussion in this subsection is for merely indicating that the system RIC has the property of fair insurance under ideal conditions.

E. The amount of compensation declared and the supply price of spectrum

As stated previously, RIC is an insurance system to spectrum users; it covers the risk of reallocation. RIC, however, is more than an insurance system, since the event of spectrum reallocation is not an unpredictable random event such as fire or earthquakes, but an outcome of the government decision of reallocating spectrum so as to minimize, aside from consideration of externalities, the total amount of compensations payment, i.e., to select those users declaring relatively low amount of compensations.

With proper incentives, of which details are discussed in Section IV, spectrum users in general tend to declare, and risk-averse users will always declare, an amount of compensation so that it is equal to the least amount of money they can accept as compensation in the event of reallocation. This means that, in effect, the amount of compensation declared by a spectrum user per unit of spectrum can be interpreted as the *supply price* of spectrum with regard to reallocation. This is the reason that we call RIC a price mechanism as well as an insurance program. Thus, RIC works as a mechanism to have the value of spectrum resources revealed in the same way as an ordinary market mechanism works as a means to have the value of goods revealed. In short, RIC is useful to the society for the same reason that the price mechanism for goods and services in general is useful to it.[13]

Figures 2(a) and (b) illustrate RIC viewed as a system of supply-price revelation. In the figures, the horizontal axis measures the size of spectrum blocks, and the vertical axis the supply price of spectrum with regard to reallocation, which is equal to the amount of compensation divided by the size of a block. In Figure 2(a), we express each spectrum block by a rectangle in the following way. First, the width of a rectangle is equal to the size of the block, and the area to the amount of compensation declared with that block. The height of the rectangle then expresses the supply price of the block with regard to reallocation. The rectangles are arranged from left to right in the increasing order of the supply prices.

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[12] See, e.g., Mas-Colell et al. [1995], pp.187-188.

[13] For the convenience of readers, we put down here the definition of the supply price and that of the demand price. The demand price of a good is the maximum amount of money that a buyer is willing to pay for obtaining the good. The supply price is the minimum amount of money that a seller is willing to accept in exchange for giving up the good. In ordinary market transactions, we observe only the price actually paid. Although this price is expected to be located near to the equilibrium price, which is determined by the demand and the supply prices (or, for this matter, the demand and the supply curves), we do not observe the demand prices of buyers or the supply prices of sellers, since buyers or sellers need not express them to conduct transactions. In RIC, however, the supply prices are expressed by all users since RIC works also as an insurance system and the users need to pay insurance premiums (compensation premiums).

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By combining the top of the rectangles, we obtain the supply curve of spectrum blocks with regard to reallocation, as shown in Figure 2(b). If the government decides to reclaim those blocks located between points O and A, then the total compensations to be paid are equal to the area OACB.

F. Implications of RIC to income distribution

In this subsection, we discuss economic implications of RIC with regard to income distribution. Since RIC is an insurance program, those users whose spectrum is reallocated receive a large amount of money as compensations, whereas the remaining users pay spectrum premiums and receive nothing. This is the consequence of RIC viewed from the standpoint of income distribution. In effect, this means that the cost of spectrum reallocation, which is expressed as an amount of compensation, is spread over, and borne by, all spectrum users.

We say that this is a desirable outcome with regard to income distribution for the following reason. First of all, the need for spectrum reallocation arises from spectrum shortage, a consequence of using the whole spectrum resources by all users. In other words, each user is responsible for the shortage by a small fraction of it. It is not economical, however, to overcome the spectrum shortage by trimming off a small fraction of spectrum from each user for reallocation; if we did this, spectrum fragmentation would come out or the cost of readjusting spectrum assignment among users would be extremely high. Therefore, to fix the spectrum shortage, we cannot avoid designating the spectrum to be reclaimed within a small range of frequencies; that is to say, we cannot avoid selecting some spectrum bands as the target for reallocation. Thus, the user of the reallocated bands is in a sense a sacrifice for all spectrum users. Compensating this user with the income collected from all users may be justified on this ground[14].

G. On implementing RIC

RIC is a system for making it possible to reallocate spectrum bands from a use of low efficiency to a use of high efficiency. The benefits of RIC, if implemented successfully, will be very large in the long run, since, at the present time, the efficiency of spectrum utilization differs massively between users. Such benefits are to be enjoyed not only by direct users of spectrum but also by their end users, i.e., by consumers.

Although RIC is a price mechanism, its implementation requires the power of the government; in short, RIC is a mandatory insurance to be imposed on all users. RIC resembles the social insurance program in this regard; it can be implemented only by a collective decision of the society. It is likely that most of the incumbent users of spectrum oppose to introducing RIC, since the compensation premium is a new burden to be imposed on them.

From the political standpoint, therefore, an implementation of RIC requires that the political power representing the benefits of RIC to the consumers be greater than that representing the opposition by incumbent spectrum users. The better the consumers understand the implications of introducing RIC, the greater the chance of a successful implementation of RIC.

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[14] Imagine a city bus running with all of its passenger seats occupied. At a stop, an old lady looking very weak got on the bus; somebody must yield a seat to the lady. This situation is like spectrum shortage.

The government, once RIC is implemented, performs two functions. The one is that of an insurance company: determining premium rates so as to maintain the long-run balance of the RIC budget. The other is to make decisions for reallocating spectrum bands as will be explained in subsections IV.B-D below. This may be done with governmental discretions or with some prescribed rules. Thus, the time-path of RIC after implementation, i.e., how fast spectrum bands will be reallocated, therefore, depends in part on government decisions.

It is noted that RIC is a system which can be designed so that the speed of implementation may be controlled by the government. It is desirable for the government to implement RIC slowly and gradually in the beginning to avoid giving excessive economic shocks to incumbents. The following is a way to do this.

In the beginning, RIC may be introduced with an extremely low level of reallocation, perhaps a zero level. Spectrum users declare an amount of compensation, but pay almost nil. During this period, a database may be constructed to store and publish information about the compensations declared together with their statistics[15]. In this way, spectrum users can learn about the level of supply prices of spectrum, if distorted because of a very low rate of premium. Oppositions by incumbent users will be minimized since there is little payment.

After a few years, say three years, the government may start executing reallocation of spectrum. The initial level of execution should be low so that the premium rate stays near zero. Spectrum users will then start feeling the burden of paying insurance premiums, and will adjust their compensations accordingly. It is expected that, as time goes on, spectrum users learn more each other and adjust compensations toward the level of truthful supply prices (the level of compensations declared honestly). After such an adjustment, the government can increase the level of executing reallocation gradually toward an "optimal" level.

To get an idea about likely magnitude of the premium rate, suppose that we reallocate 30MHz of spectrum annually out of the crowded below-3GHz bands. A simply calculated rate on an unrealistic assumption that the supply prices are equal over all spectrum bands would be 1.0% = 30MHz/3GHz per year. This sets an upper bound of premium rates.

In general, suppose that the below-*K*-GHz spectrum has a linear supply curve with the lowest price (a) and the highest price ($a+b$). See Figure 2(c). (Note that the blocks are rearranged on the horizontal axis in the increasing order of supply prices.) If a 100s % of the blocks of *K*-GHz is reclaimed annually, then the total compensations declared (C), the annual compensations paid (M), and the annual premium rate (r) will respectively be as follows:

$$C = \left\{ a + \tfrac{1}{2} b \right\} * K,$$

$$M = \left\{ a + \tfrac{1}{2} s * b \right\} * (sK),$$

[15] Note that such a database may be built on top of the database used for storing information of individual licenses currently.

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$$r = \frac{M}{C},$$

$$= \frac{a + (1/2)s * b}{a + (1/2)b} * s.$$

If b=0, then r=s, which is the case of equal supply prices as mentioned above. If K=3GHz, s=0.01, a=1, and b=10, then sK=30MHz and r=0.00175. This means that, if the highest supply price is ten times greater than the lowest supply price and if the supply curve is linear, then annual reallocation of 30MHz of spectrum out of the 3GHz (i.e., one per cent reallocation annually) implies a premium rate as low as 0.175% per year.

We note, before closing this subsection, that RIC is a grandfathering system over spectrum assignment; thus, it can be implemented regardless whether the assignment is under command and control or market mechanism, and regardless whether the utilization mode is exclusive, club, or commons. It can be implemented for a case in which any factors of the above are mixed, although the performance of RIC depends on them, as explained in the following section.

III. RIC and Alternative Ways for Spectrum Assignment

A. Club or commons

In this section, we examine the functioning of RIC when it is associated with alternative systems for spectrum assignment. First, we consider how RIC works when a spectrum block is used in club or commons mode. In this case, a spectrum block is assigned to multiple users; it may be offered freely to the public as commons, or the entry by new users may be restricted by means of, say, licensing (as in amateur wireless) or by some other qualifications (as in a band used for the safety of navigation or aviation). For all of these cases, we expect that RIC works quite well[16].

When RIC is implemented, club or commons users understand and accept that the spectrum they are using may be reclaimed for reallocation. Each user can declare an amount of compensation which will be paid in the event of reallocation. Compensation may be declared by means of direct registration with the government, or, if so chosen, by means of a declaration with a slip to be obtained at the time a device is purchased for using a club or commons block. For example, users of an electro-magnetic heater may wish to pay in one installment the compensation premiums for the period of expected duration of the equipment (e.g., for 10 years); the amount of compensation may be set to reflect the purchase price of it, or, alternatively, the actual value of the

[16] For the case of a club or commons, the distinction between allocation and assignment becomes unimportant, since a band is often composed of a single block, to which multiple users are assigned. We use, in such a case, the two terms of allocation and assignment interchangeably.

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equipment at the time of spectrum reallocation (e.g., 30% of the purchase price if the device becomes useless because of reallocation in the 7-th year of the 10-year duration period).

The total amount of compensations that the government needs to pay for reclaiming a club or commons block is equal to the sum of the declared compensations by all users of the block. Since spectrum club is a club good and spectrum commons is a public good, this is a case of the Lindahl-Samuelson valuation of club or public goods. In other words, the value of a club or commons block is expressed by the sum of the prices attached by all users of that block.

In conclusion, we can state that RIC is expected to work well with club or commons assignment, of which reallocation is extremely difficult usually.

B. Market mechanism

When spectrum is assigned under market mechanism, RIC is expected to work very well. The government allocates a band for exclusive use with specific objectives. Spectrum may be a private property; in this case, the right to use a block can be traded or leased in the market. Alternatively, spectrum may be retained as a government property; in this case, a block is leased competitively to users, and the lease right may be traded in secondary markets. In any case, the value of a spectrum block is expressed by a property price or a lease price.

Spectrum users and the government can take spectrum prices into account in making RIC decisions. Spectrum users can choose an amount of compensation in the event of reallocation by considering market values of spectrum blocks. For example, the estimated cost of acquiring a replacement spectrum in the event of reallocation is a useful data in calculating the amount of compensation.

The government can use market values of spectrum bands in making decisions on reallocation. For example, if the price of a spectrum band devoted to a particular objective is high relative to other objectives, then the government should consider to reclaim spectrum bands with low prices so as to increase the size of the band with a high price.

In short, RIC is a price mechanism for reallocating spectrum resources; hence, it is expected to work well when spectrum assignment is under market mechanism, which can provide the value of spectrum in the form of property or lease prices.

The usefulness of RIC with assignment under market mechanism, however, may appear not so high as that under club, commons, or command and control, since market mechanism supposedly accomplishes efficient use of spectrum within a given allocation. What RIC is useful is for the case in which a change in spectrum allocation (i.e., reallocation) is needed. The function of RIC in this regard may be compared to that of city planning (such as zoning) in using land resources. Observe that, when assignment is under club, commons, or command and control, RIC often accomplishes reassignment as well as reallocation, whereas RIC with assignment under market mechanism can correct spectrum inefficiency only through reallocation.

Further, it is possible that, in the future, market transactions of spectrum may replace some of the functions of RIC, especially when positive externalities in using spectrum are weakened as a

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consequence of technological progress and the government deregulates technological restrictions on the use of spectrum in accordance with such technological progress. If this becomes reality, the functions of RIC, as a government-run price mechanism, will be replaced gradually by the functions of free markets, in which the right to use spectrum is traded without governmental controls.

C. Command and control

When spectrum assignment is made under command and control by a government, RIC still works, but not so smoothly as in the case in which assignment is made under market mechanism. Despite that, the usefulness of RIC may be greater than in the case of assignment under market mechanism as stated in the preceding paragraph. In command and control, the government assigns spectrum blocks to users on the first-come base, comparative hearings, or random selection. Licenses are renewed automatically. Spectrum usage fees may be charged by the government, but the level of fees stays far less than the market value of spectrum. Hence, there is an excess demand for spectrum resources, which the government resolves by means of command and control.

Spectrum users under command-and-control assignment with RIC declare compensations and pay premiums, and receive compensation payments in the event of reallocation. Spectrum users, in this case, may need to calculate an amount of compensation with a great deal of uncertainty; they may need to guess the intention of the government. For example, if a user is given a replacement block by the government after reallocation, then the amount of compensation will be the cost of moving from the current block to the replacement block[17]. If a user is not given such a replacement block after reallocation but the activities of the user can continue with some other means (e.g. by using optical fibers to replace wireless communication), the amount of compensation will depend on the switching cost (from wireless to fibers). If the activities cannot be continued without using spectrum, then the compensation should include the cost of terminating the activities.

When spectrum reallocation is made under command and control, i.e., without RIC, the government has in some way to collect data expressing the value of spectrum in use. In particular, the government has to make a decision on both the size and the location of spectrum bands to be reallocated for new objectives, and this has to be done in the opposition by incumbent users. In contrast to this, RIC can help the government find spectrum bands to be reclaimed for reallocation. Note, however, that RIC by itself does not provide the government with information where spectrum bands should be reallocated to.

D. RIC and end users of spectrum

In many cases, spectrum is used directly and indirectly. Mobile operators supply mobile telephone services to subscribers by means of wireless technology; in this case, mobile operators are direct users and subscribers are indirect users; we call the latter *end users*. Likewise, TV stations use spectrum directly for broadcasting and consumers viewing TV are end users of spectrum. In this subsection, we consider how RIC works with end users. We call users of spectrum that are not end users such as mobile operators and broadcast stations *intermediate users*.

First of all, we point out that intermediate users of spectrum provide their services to end

[17] See subsection V.B for details.

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users usually in club or commons mode. Mobile telephone operators form, in effect, a club of mobile subscribers to have them share spectrum for mobile telephony. Consumers watch TV programs by using spectrum as commons which is provided by broadcast stations. Thus, it is possible to use a RIC framework when intermediate spectrum users deal with end users with regard to termination or modification of the service in the event of spectrum reallocation. This may be explained by means of examples as follows.

Consider intermediate spectrum users such as a wireless Internet access provider serving Internet subscribers or a mobile operator serving mobile telephone subscribers. Intermediate spectrum users (operators) can offer a RIC-like arrangement (contract) to their customers (Internet or mobile telephone subscribers). Then, the total amount of compensations to be paid by an operator to customers in the event of reallocation would be the sum of the compensations claimed by all customers. Therefore, the amount of compensation that an operator should declare with the government in the event that the block is reallocated is the sum of the compensations to be paid to all customers for terminating the service plus the cost of reallocation incurred directly to the operator[18]. Mobile or Internet subscribers may declare an amount of compensation and pay a premium at the time they begin subscription or they purchase devices. This is similar to paying for the seller's guaranteeing a device from breaking down.

For the case of free-to-air broadcasting, consumers use broadcast spectrum as commons; hence, RIC with commons as explained in subsection III.A applies. For paid TV, consumers use broadcast spectrum in the club mode. A RIC-like contract may be formed between a broadcast station and end users of spectrum (consumers).

Thus, once RIC is introduced, then it will induce RIC-like arrangements between intermediate and end users of spectrum; we can expect that spectrum reallocation may be accomplished without serious troubles with end as well as intermediate users.

IV. Decisions by Government and the Behavior of Users with RIC

A. Outline

In this section, we consider the decisions to be made by the government and the behavior of users in RIC. Since RIC is a price mechanism, it can provide with information about the value of spectrum in use, which is useful for the government and users to make decisions. The government can select spectrum bands to be reallocated so as to minimize the amount of compensation payments. The government, however, needs to consider other factors such as positive externalities between spectrum bands and needs to make discretionary decisions.

RIC may induce speculation and manipulation because of this. Users may declare an amount of compensation honestly so that it is equal to the minimum amount of money for yielding the right to use spectrum (that is, the truthful supply price of spectrum with regard to reallocation), but, of

[18] Note that the consequence of reallocation need not be limited to a termination of the service; a RIC-like arrangement with customers such as a transfer to another block is conceivable. See subsection V.B.

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course, users can speculate by declaring an amount exceeding the truthful supply price in order to harvest extra revenues in the event of reallocation. Such a user, of course, loses if the user's spectrum is not reclaimed. It is desirable to prevent such speculation so that the users reveal truthful supply prices for the following reasons. (a) Speculation distorts supply prices and causes inefficient reallocation of spectrum. (b) Speculation produces uncertainties to the government and users. (c) Speculation incurs additional transactions cost to the government and users.

The discussion in this section proceeds as follows. First, we consider decisions by the government for reallocation with the assumption that the users are honest and do not speculate on compensations. Second, we discuss factors which induce users to speculate. Third, we consider policies useful for the government to prevent speculation.

B. Decisions by government on the size of spectrum bands to be allocated for new objectives

In this subsection, we deal with the question whether a particular spectrum band should or should not be reallocated by government for a new objective of use in the case that spectrum users reveal supply prices truthfully.

Roughly speaking, the government should attempt to reallocate a band from a low-efficiency use to a high-efficiency use. To express this more precisely, let us define the *efficiency-improvement index* of reallocation for each spectrum band and for each new objective in the following way:

(the efficiency-improvement index) = (PVN – Comp) / PVC, where

PVC = (the present value of a band with the current use),

PVN = (the present value of the band with a new use), and

Comp = (the compensations to be paid for reclaiming the band).

A band should be reallocated only if the efficiency-improvement index is greater than 1.

In practice, the government can make reallocation decisions in the following way. First, the government establishes a set of new objectives to which spectrum bands may be allocated (reallocated). Second, the government lists the spectrum bands currently in use in the decreasing order of the efficiency-improvement indices. Note that a band used currently may have more than one efficiency-improvement indices if more than one new objectives are attached to it. Third, for each new objective, the government forms a list of spectrum bands currently in use with efficiency-improvement indices greater than one. That is to say, to each new objective is attached a list of spectrum bands in use which are candidates for reallocation. Forth, the government makes decision, for each new objective, to what extent reallocation is to be made; i.e., the government specifies the size of spectrum bands to be allocated to each new objective. The process described above should be applied to all spectrum bands currently in use regardless whether a band is assigned under command and control or with market mechanism, or whether the mode of utilization is exclusive, club, or commons.

Figure 3 is an example of the matrix of efficiency-improvement indices. Spectrum bands are denoted by numbers, which appear on the top row of the matrix. Objectives for spectrum use are named by alphabetical letters, of which A, B, C, … are for current objectives and X,Y, Z,… are for new objectives. An entry a_{ij} of the matrix is the efficiency improvement index of band *i* with objective *j*. In the upper half of Figure 3, a cell with bold frames has an entry for the current use, which is equal to 1 by definition. Cells in the lower half are efficiency-improvement indices with new uses. For example, a_{1X} is the index when band 1, which is used for objective A currently, is reallocated to the new objective X. A cell with bold frames in the lower half is a candidate for reallocation. For example, the index a_{2X} is greater than 1 and also greater than other indices (such as a_{2Y}) in column 2 of the lower half; band 2 may be considered for reallocation from current objective B to new objective X. Thus, for each new objective, the list of bands with bold-framed cells gives its candidates for reallocation.

When, on the one hand, spectrum blocks are assigned with a market mechanism, the present value of using a band for the current objective of use as well as for a new objective can be calculated by using market prices of spectrum, although the government still needs to estimate the expected rate of return from using a band for the new objective. In doing such estimation, the government cannot avoid making some discretionary decisions. In spite of that, we can say that reallocation decision by the government involves a minimum amount of discretions if spectrum assignment is conducted with a market mechanism.

On the other hand, when spectrum blocks are assigned under command and control, the present value of a spectrum has to be calculated without using market prices; the amount of governmental discretions is far greater than in the case with market mechanism. Further, for this case, we expect that there will likely be disputes and delays in making decisions on reallocation; thus, the organizational cost (transactions cost) of decision making for reallocating spectrum is greater in the case of command and control than in the case of market mechanism.

C. Possibility of speculative behavior by users

One of the desirable properties of RIC is that it can prevent spectrum hold-up. As known from our experiences in reallocating land, it is possible for an owner of a space resource (such as land or spectrum) to attach an extremely high amount of compensation for reallocation in an attempt to acquire extra revenues. Holding-up a piece of space-type resource is quite effective when it is located in the middle of a large-sized space which is about to be reclaimed. This is an outcome of positive externalities in using land or spectrum resources; the social cost arising from holding-up maybe very high.

RIC has the power to avoid such hold-up. The government will choose a band to be reallocated so as to minimize the amount of compensation outlays. Hence, when a spectrum user attaches a high compensation to a block, it is likely that the band with this block will not be chosen for reallocation. Then, the user attempting to hold-up a block will continue with paying a large amount of spectrum premiums for nothing. In other words, in RIC, spectrum hold-up is not a profit-making choice; it tends to be a losing choice.

This discussion may be over-simplified. Actual outcomes from a speculative and manipulative behavior by spectrum users in RIC may depend on other factors. We will discuss

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some of these in the following subsection.

D. Decisions by government on the selection of spectrum bands to be reallocated

In general, selection of spectrum bands to be reclaimed for reallocation should be done by government with a criterion of minimizing the amount of compensation outlays; that is to say, spectrum bands to be reclaimed for reallocation should be chosen from those users declaring a relatively low amount of compensations. In practice, however, selection of spectrum bands to be reclaimed cannot be done mechanically according to a simple formula because of the presence of positive externalities. It is advantageous for the government to organize a set of spectrum bands to be allocated for new use in such a way that the bands are located contiguously or within a relatively narrow range of frequencies. But this could invite speculation and manipulation by spectrum users in declaring an amount of compensation.

A typical case for a spectrum user to declare an amount of compensation speculatively for making extra revenues may be like the following. Such a user would seek a spectrum block located strategically with regard to the amount of compensations declared by other users. When the amount of compensations declared is relatively low for blocks located near to a strategic one, then because of positive externalities, the probability that the strategic block is reclaimed is high even if it carries a relatively high amount of compensation. A speculative user would seek such profit-making opportunities, which will be a factor disturbing smooth functioning of RIC.

Figures 4(a)(b) illustrate such a speculation. In the graph of Figure 4(a), the horizontal axis measures the quantity of spectrum blocks, and the vertical axis the efficiency-improvement index. In Figure 4(a), five blocks of different sizes are depicted, to each of which an efficiency-improvement index is attached on an truthfully-declared compensation. Suppose that these blocks are in a band which is a candidate for reallocation. Suppose that the third block is of small size relative to the others; it can then be a strategic block. The user of this block may speculatively declare a large amount of compensation; then, its index will be low, as shown in Figure 4(b). If the government makes a decision solely on the total amount of compensations, the band of these five blocks may still be chosen to be reclaimed, since the increase in the compensations due to the speculation may not be large; the speculation will succeed.

To avoid such speculations and accompanying disturbances, the government should follow the following strategies. First, the government should allow spectrum users to revise the amount of compensation declared from time to time. Further, the government should disclose all information about the amount of compensations declared and give ample time for users to revise their declarations before executing a reallocation. In this way, speculative declaration will be eliminated gradually through competition among spectrum users. For example, users of blocks near to the block with a speculatively declared compensation will attempt to increase their compensations in order to get a share of extra revenues from a successful speculation. This, however, will decrease the chance that the blocks are reclaimed, and the users of these blocks will be “defeated” by other users with less speculative declarations. This suggests that the government should consider, in deciding whether or not to reclaim a spectrum band, such indicators as the variance of declared amounts over the blocks in the band and the variance of declared amounts of a block in the band over time. It is for future research to devise an algorithm providing the government with decision rules for actually reclaiming blocks.

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E. Determination of the amount of compensation by users

In this subsection, we consider the behavior of a non-speculative profit-maximizing user of spectrum in determining the amount of compensation. We assume that speculative declaration does not arise because of government regulations and competition among users. Then, the amount of compensation declared will be the minimum amount of money for which a user is willing to yield the right of using a spectrum block. Roughly speaking, this amount will be determined according to the following equation;

(the amount of compensation for reallocation)

= (the present value of future incomes with the current business without reallocation)

– (the present value of future incomes with a new business after reallocation) + Q, where

Q = (the once-and-for-all cost of changing business because of reallocation).

It is noted that the present value of future incomes with the current business without reallocation is assumed to be known to the user. Regarding the present value of future incomes with a business after reallocation, there will usually be multiple choices (even if we exclude speculation). The once-and-for-all cost of changing business will vary depending on the choice of a new business. One possibility is to terminate the current business without a new business after reallocation; in this case, the second and the third terms of the right-hand side of the equation will become zero. In general, the amount of compensation to be declared, then, depends on the choice of a new business by the spectrum user. This decision is to be made by the user in a domain which includes factors not related to spectrum use. In other words, the equation stated above presupposes that this decision has already been made by the user.

V. Extensions of RIC

A. Introduction of multiple reallocation periods

This subsection is devoted to considering a form of RIC with multiple reallocation periods. *Reallocation period* is the time period between the decision of reallocation and its execution (the termination of spectrum utilization)[19]. In general, the cost of reallocation, to be revealed in the amount of compensation in RIC, may greatly depend on the choice of a reallocation period. It is advantageous both for spectrum users and for the society as a whole to introduce multiple reallocation periods so that the actual reallocation may be made with a reallocation period of minimum cost. The system introduced in this subsection is a RIC in which spectrum users can reveal their preferences over multiple reallocation periods.

Let us consider, as an example, a case with six different reallocation periods: 0-year period,

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[19] The Japanese government, in reallocating a small number of spectrum bands under command and control (i.e., not under RIC) during recent years, gave spectrum users an allowance of ten years or so in average as the reallocation period.

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1-year period, …, 5-year period; the 0-year period corresponds to the case of single-reallocation period. Spectrum users are allowed to declare an amount of compensation for each of the six reallocation periods. It is convenient to organize the declaration of compensations in the following way. First, the user declares a compensation for reallocation with 5-year period. Next, the user declares a compensation for *decreasing* the reallocation period by one year from 5 to 4 years. The compensation for reallocation with 4-year period is the sum of the 5-year compensation and the compensation for the one-year decrease. The compensation for each of 3, 2, 1, and 0-year periods are declared similarly. See Figure 5. The compensation for reallocation with 0-year period is, as stated above, equal to the one for the single reallocation period. Thus, this arrangement expands the domain of events on each of which an amount of compensation is to be declared without charging additional compensation premiums to be paid by users; i.e., this is a costless generalization of the system to users and the government (aside from transactions cost).

Thus, spectrum users can exhibit their preferences over six different reallocation periods by means of an amount of compensation attached to each reallocation period. If it is convenient for a user to have, say, 3-year reallocation period (for the reason that, say, the average depreciation period of the devices in use is 3 years), the amount of compensation attached to the 3-year period will be far less than the compensations attached to the 2, 1, and 0-year periods.

The principle according to which the government sets premium rates in this system is still the long-run balance of the RIC budget. A single premium rate should be applied uniformly to the six reallocation periods.

In this system, the decision by the government on the selection of the band to be reallocated will be a little more complicated than the system of single reallocation period. Roughly speaking, it is a five-year plan for reallocation decisions (i.e., announcements) to be revised each year. That is to say, in each year, the government selects spectrum bands to be reclaimed in each of the five years to come and add them to the bands having been decided to be reclaimed in the five-year plan. The principle of minimizing the total amount of payments for reallocation should be observed for each year.

B. Introduction of compensation in kind

In this subsection, we consider the possibility of introducing (partial) *compensation in kind*, that is to say, a case in which users are assigned a block of spectrum as a *replacement* of the block reclaimed for reallocation. In fact, this type of compensation has been used in many countries for reallocating spectrum under command and control. It was useful during the period in which the frontier of spectrum resources was expanding and new spectrum bands became available one after another thanks to technological progress. In the time of spectrum shortage, however, it may not be so easy for the government to find new spectrum bands for compensation in kind. The system of RIC to be presented below may be useful for the case in which spectrum assignment is still under command and control and the government can find replacement spectrum blocks without much difficulty (e.g., in high-frequency bands). In the following, we introduce a system for compensation in kind, which lets users reveal preferences over different degrees of replacement in a way similar to the system of multiple reallocation periods, as explained in the preceding subsection.

In this system, the government first prepares spectrum blocks to be used for replacements.

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Spectrum users are allowed to declare an amount of compensation with different degrees of replacement expressed by the percentage of the size of a replacement block to the size of the block to be reclaimed. For example, suppose that a user is given six such choices: replacement of 100%, 80%, 60%, 40%, 20% and 0% (no replacement). The user first declares a compensation with a 100 % replacement, and then declares a compensation for *deceasing* the percentage by 20% from 100% to 80%, and so on; the last is for the one deceasing from 20% to 0%. The sum of the six figures of these declarations is equal to the compensation for reallocation without a replacement. See Figure 6. Observe that this system includes the system of no replacement as a special case; in particular, the amount of compensation premiums paid in this system would be unchanged from the system with no replacement. Thus, this system gives to both the users and the government additional possibilities of choices in relation to spectrum reallocation.

The government, given the preferences of users with regard to replacement, makes a decision as to the percentage of replacement to be granted to each user. The sum of replacement blocks is limited by the size of spectrum available for replacement; the criterion for deciding a degree of replacement should be minimization of the sum of the amount of compensation paid to the user plus the value of the replacement block awarded. Considering a decision rule for the government in detail is left for future research.

Users can exploit the benefit of this arrangement in the following way. First, observe that users may decide to introduce new spectrum devices by replacing old ones; the amount of money received for compensation may be spent on new devices. Second, newly introduced devices may let users save the size of spectrum blocks necessary to maintain their activities at the same level as before the reallocation. Observe further that this system will let users choose an optimal combination of spending on new devices and saving spectrum resources, and that such an arrangement will provide a strong incentive for inventing new devices for saving spectrum resources.

Observe further that by combining this system with the system of multiple reallocation periods (as explained in the preceding subsection), it becomes possible for the government to reallocate spectrum with replacement efficiently. In particular, the government can plan reallocation with replacements a few years ahead of execution. Such a plan would give ample flexibility to users so as to make adjustments necessary to reallocation without incurring much cost, and let the government minimize the loss arising from the need to leave spectrum blocks vacant at the time of switching users.

Figure 7 explains this. Suppose that, at time t_0, a reallocation decision (A1,(t_0)) is made to the effect that spectrum block 1, which is assigned to user X, is to be reassigned at time t_1 ($t_0 < t_1$) so as to decrease the size assigned to X (with a possible compensation). Given this decision, the government makes at time s_0 ($t_0 < s_0 < t_1$) another reallocation decision (A2(s_0)) to the effect that (1) the assignment of block 2 to user Y is to be terminated at time s_1 ($t_1 < s_1$) with a replacement which is the part of block 1 vacated according to A1(s_0) (with possible compensation), and (2) block 2 is to be assigned to new user Z at time s_2 ($s_1 < s_2$, but s_2 may be very close to s_1). Observe that the decisions A1(t_0) and A2(s_0) make it possible to reallocate the two blocks 1 and 2

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smoothly[20].

VI. RIC for International Reallocation of Spectrum (IRIC)

A. International reallocation of spectrum

In this section, we consider the possibility of applying RIC to international reallocation of spectrum; the system to be introduced below will be called International RIC (*IRIC*). IRIC, if implemented successfully, will give the international community the same type of benefits in spectrum reallocation as RIC gives to a country.

At the present time, international allocation and reallocation of spectrum resources is governed by international organizations such as the International Telecommunication Union (ITU). Decisions in ITU are made mainly on negotiations by member countries. Because of the conflict of interests among member countries, it is often difficult to reach an agreement in ITU. Difficulty is expected to be greater in reallocating spectrum currently in use than in allocating spectrum anew. In short, ITU, as an organization responsible for international allocation and reallocation of spectrum resources, has been encountered by the same difficulty that national government has. The system introduced below is a way to solve this problem. (We will use the terminology ITU in this section to express an international organization. The discussion applies to other international organizations as well.)

B. Outline of IRIC

Let us first explain how IRIC works for international reallocation of spectrum bands. It is similar to the way in which RIC works within a country. In IRIC, the role of national government in RIC for domestic reallocation will be played by ITU for international reallocation. The role of users in RIC will be played by member countries in IRIC.

Thus, a member country specifies an amount of compensation for each spectrum band in the event that the band is reallocated by ITU. Member countries pay compensation premiums to ITU according to the IRIC premium rate determined by ITU. Member countries receive compensation payments for reallocated bands.

ITU, in this system, maintains an IRIC budget for premium collections and compensation payments. ITU determines an IRIC premium rate so as to maintain the long-run balance of the IRIC budget.

Decision by ITU with regard to reallocation is composed of two steps as in domestic RIC. The first step is to recognize the need for spectrum for new objectives of utilization. This may still

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[20] It is possible to introduce a RIC in which a user can declare an amount of compensation for each combination of a reallocation period and a percentage of replacement, even if the preferences of the user are not independent over reallocation periods and percentages of replacement. For example, a user may prefer strongly over others the combination of the 3-year period and the replacement of 50% because of technological characteristics of devices to be introduced with reallocation.

be done on negotiations, although it is expected that, with IRIC, member countries can make reallocation decisions on data which would be unavailable without IRIC. The second step is to determine where to obtain spectrum bands to be reclaimed. The principle which ITU should rely on is the same as in domestic RIC: minimization of the amount of compensations to be paid for the reallocation with consideration of positive externalities.

Thus, the way in which IRIC works is almost identical to the one RIC works. It is noted that the premium payment and the compensations receipts by a member country with ITU does not necessarily balance; in short, there are international transfer of income as a consequence of reallocation under IRIC in the same way that there are inter-user transfer of income under domestic RIC. Observe that, in any international reallocation of spectrum bands, we cannot avoid some countries from being benefited and some other countries from receiving damages; in other words, there is no international reallocation of bands sacrificing no country. International transfer of income is a means to compensate such a sacrifice; it is a means to realize international reallocation of spectrum resources beneficial to the world as a whole.

C. ITU and member-countries (1/3)

In the remainder of this section, we consider three cases which arise depending upon whether or not IRIC is adopted by ITU and also whether or not RIC is adopted by member countries. We first consider the case in which ITU adopts IRIC and member countries adopt RIC. Since both IRIC and RIC are price mechanism, the two together will function quite well.

In this case, national government with RIC aggregates the domestically declared compensations for each band and registers the sum of the compensations with ITU. The government applies the ITU premium rate to the domestic users, collects compensation premiums from domestic users, and pays the sum of the domestic premiums collected to ITU. Further, the government distributes the compensation payments received from ITU for reallocated bands to domestic users according to the amount declared by each of them.

Thus, in short, the role of the national government with regard to reallocation of spectrum becomes transparent between ITU and domestic users. The net outcome to domestic users in this case is the same as the outcome in the case in which domestic users dealt directly with ITU (without intermediation by a national government). Figures 8(a) and (b) illustrate the transactions between the national government and the users before and after a reallocation decision.

It is possible, however, that the domestic government still executes reallocation of spectrum bands under its own domestic RIC separately from IRIC. The users in this case will pay two compensation premiums, one for IRIC and the other for domestic RIC. There will be reallocation of spectrum bands and accompanying compensations due to IRIC and reallocation and compensations due to domestic RIC. This is like our dealing with national and local governments simultaneously in paying taxes and receiving public services. See the left-half of Figure 8(b).

D. ITU and member-countries (2/3)

Next, we consider a case in which ITU adopts IRIC but a member country does not adopt RIC. That is to say, domestic reallocation of spectrum in the country is done under command and control by the national government.

First, note that the national government, a member of ITU, must follow the IRIC rules in ITU; the government declares an amount of compensation for each band to ITU, pays compensation premiums to ITU, and receives compensation payments for spectrum bands reallocated by ITU. In determining an amount of compensation to be declared for each band, the domestic government needs to aggregate the preferences of domestic users with regard to reallocation into an amount of money. The work to be done by the national government for doing this is of the same order of magnitude as in the work by the national government preparing for negotiations in ITU without IRIC, i.e., as in the current situation. The only difference is that, in the current situation, the national government expresses in ITU the aggregate preferences of the domestic users in the form of opinions and statements possibly with data, whereas, in the case under consideration, the national government expresses the aggregate preferences of the domestic users in the form of an amount of money.

For this case as well as for other cases with IRIC, the amount of payment by the national government to ITU as reallocation premiums is not necessarily equal to the amount of money that the government receives from ITU as compensation payments. It is expected, however, that the difference is far less than the gross payment or receipt by the national government with ITU.

E. ITU and member-countries (3/3)

Finally, we consider a case in which ITU does not adopt IRIC but there are member countries adopting RIC domestically. Spectrum allocation and reallocation in ITU will be determined by member countries through negotiations. The government of a country with domestic RIC has information about the supply prices of domestic spectrum bands at hand; the government can use this information in participating negotiations in ITU. The burden to the domestic government arising from the need for aggregating the preferences of the domestic users is far less than in the case without domestic RIC. Further, the government with domestic RIC can execute spectrum reallocation agreed upon in ITU smoothly by using the domestic RIC.

In addition to the above, we point out that there is a possibility for some of member countries with domestic RIC to form a group within ITU for spectrum reallocation. We call it the group of countries for IRIC (*GIRIC*). See Figure 9. The GIRIC member countries may execute IRIC within GIRIC; it is like forming a Free Trade Agreement (FTA) in the world in which free trade does not prevail globally. In this case, the GIRIC member countries will enjoy the benefits of IRIC within GIRIC.

Even though GIRIC does not implement actual IRIC within itself, the GIRIC member countries can still assemble information from their domestic RIC to be used for the benefits common to them. A way to do this is to conduct a simulation of IRIC within GIRIC without actual premium collections or compensation payments for spectrum reallocation. The outcome of such simulated IRIC within GIRIC may be used to form an opinion by the GIRIC member countries for negotiations in ITU. The possibility that a reallocation plan preferred by the GIRIC member countries is agreed upon in ITU will be increased by this. In short, the GIRIC member countries use their domestic RIC as a means to collect information about the value of their domestic spectrum bands, and then to aggregate such information for the benefit of the GIRIC member countries. This is an example of the informational benefit of RIC and IRIC as a price mechanism.

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VII. Conclusions

In this paper, we proposed and described RIC as an economic mechanism to reallocate spectrum resources. We note that RIC can provide with an economic basis for defining an extent of legal right of using a resource such as spectrum. On the one hand, spectrum can, though need not, be used exclusively and privately in the same way as ordinary goods are; hence, it is possible to form a property right on spectrum. On the other hand, unlike ordinary goods, spectrum as a resource has externalities; if we allow an unlimited property right on it, we may end up with an inefficient use of spectrum for the society as a whole, even though each piece of spectrum is used efficiently from the standpoint of individual users. This is the reason that we need to have a system for reallocating, as opposed to reassigning, spectrum. In other words, we should introduce a right to use spectrum limited for efficient use of it for the society as a whole, and the limit to the right is the obligation for individual users to accept reallocation.

Now, reallocation may be realized directly by the government, i.e., by command and control; it may also be realized by an economic mechanism which is compatible with individual incentives. RIC is one of such mechanisms; it combines a system of insurance and compensations with a system of supply-price revelation.

It is seen that RIC as such may be applied to the use of resources other than spectrum with excludability and externalities. Land and other space resources are immediate examples. Another example may be subscription to legacy telephony (as opposed to IP telephony). Consideration of this topic is left for research in the future.

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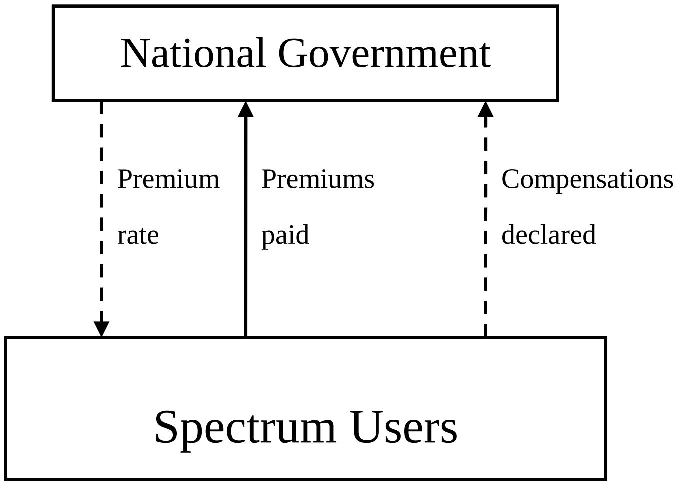

Figure 1(a): Insurance and Compensation for Reallocation

(before reallocation decision)

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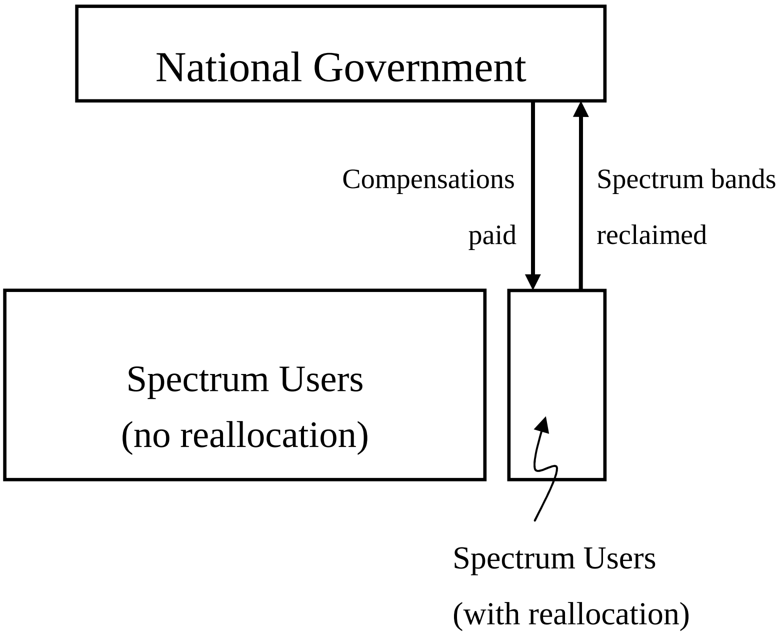

Figure 1(b): Insurance and Compensation for Reallocation

(after reallocation decision)

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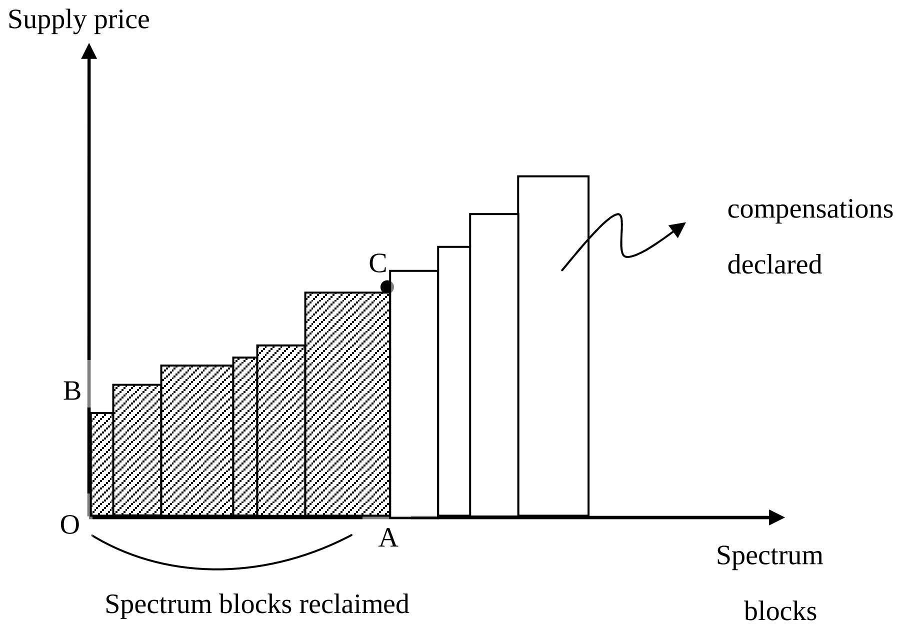

Figure 2(a): Supply of Spectrum Blocks with regard to Reallocation (1/2)

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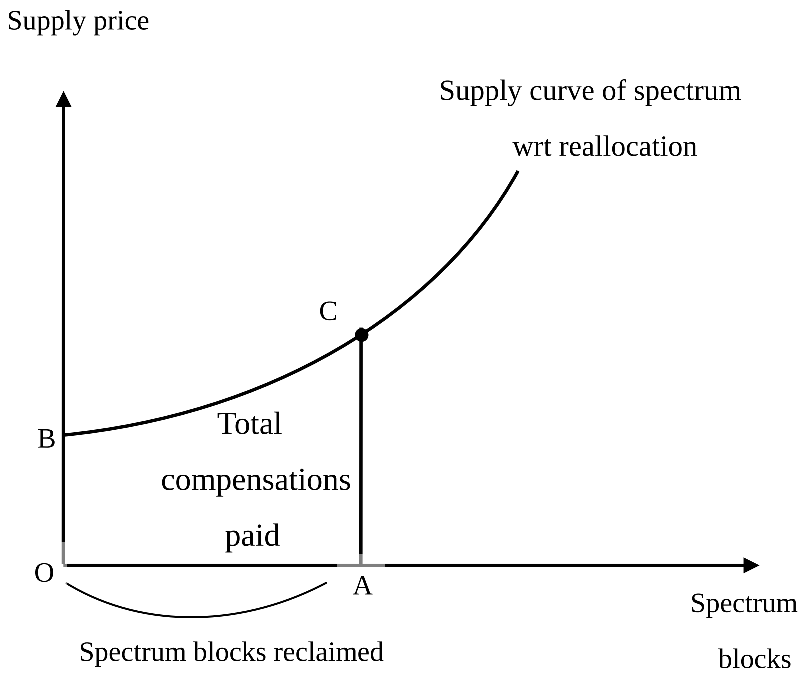

Figure 2(b): Supply of Spectrum Blocks with regard to Reallocation (2/2)

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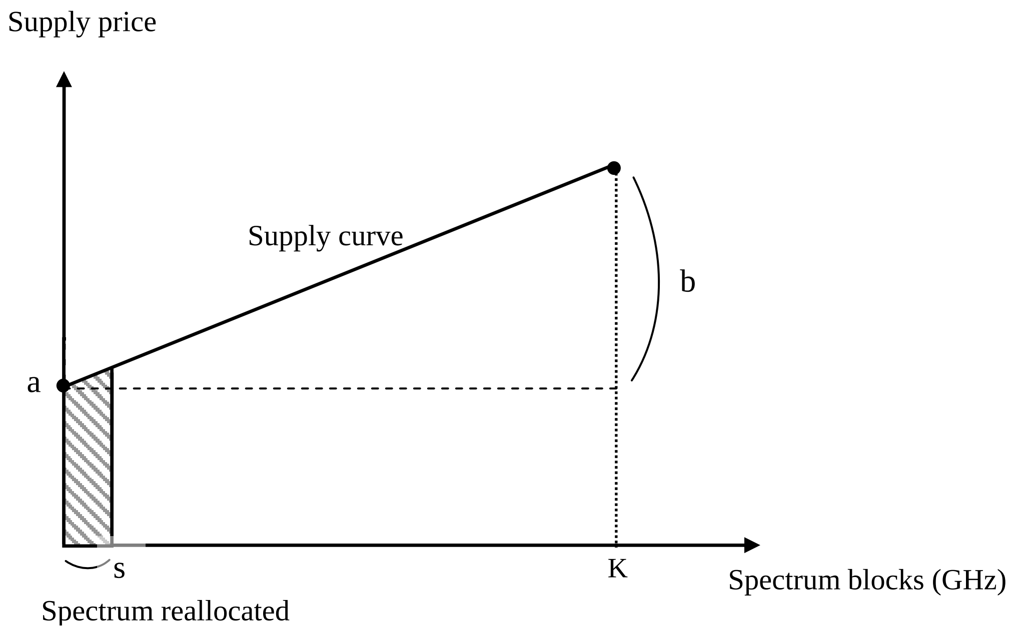

Figure 2(c): Calculation of Premium Rates with Linear Supply Curve

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Objective of Use \ Spectrum Band		1	2	3	4	· · · · ·	· ·
Current Objectives	A	a_{1A}					
	B		a_{2B}				
	C			a_{3C}	a_{4C}		
	⋮						
	· ·						
New Objectives	X	a_{1X}	a_{2X}	·· ·	· ·	· · · · ·	· ·
	Y	a_{1Y}	a_{2Y}				
	⋮	· ·	· ·	· ·	· ·	· · · · ·	· ·

Note: $a_{1A} = a_{2B} = a_{3C} = a_{4C} = 1$.: current allocations
a_{2X} : candidate for new allocation (reallocation),
where $a_{2X} >> 1$ and $a_{2X} > a_{2Y}$.

Figure 3: Matrix of Efficient-Improvement Indices

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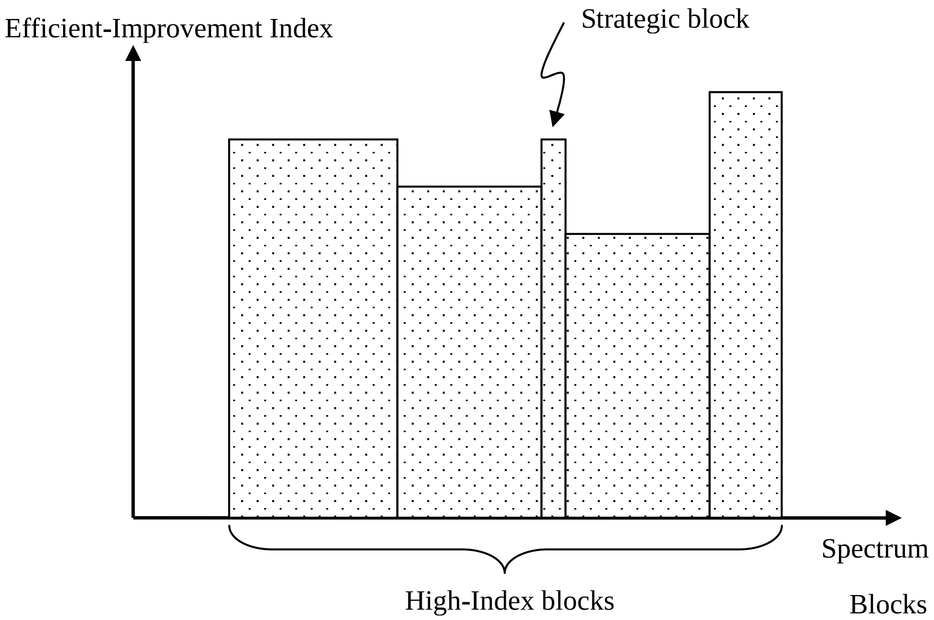

Figure 4(a): Distribution of Efficient-Improvement Indices with Honest Declaration

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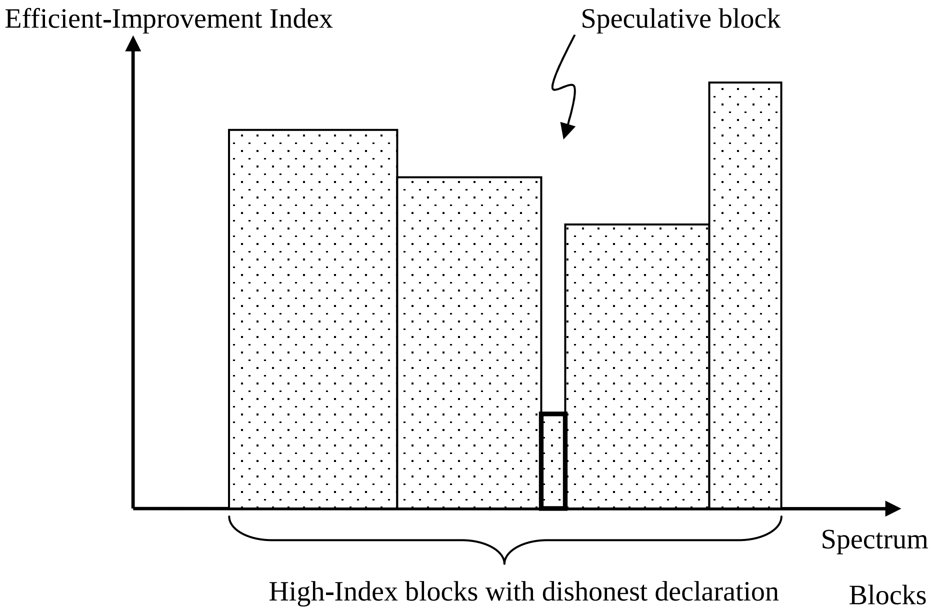

Figure 4(b): Distribution of Efficient-Improvement Indices

with False and Speculative Declaration

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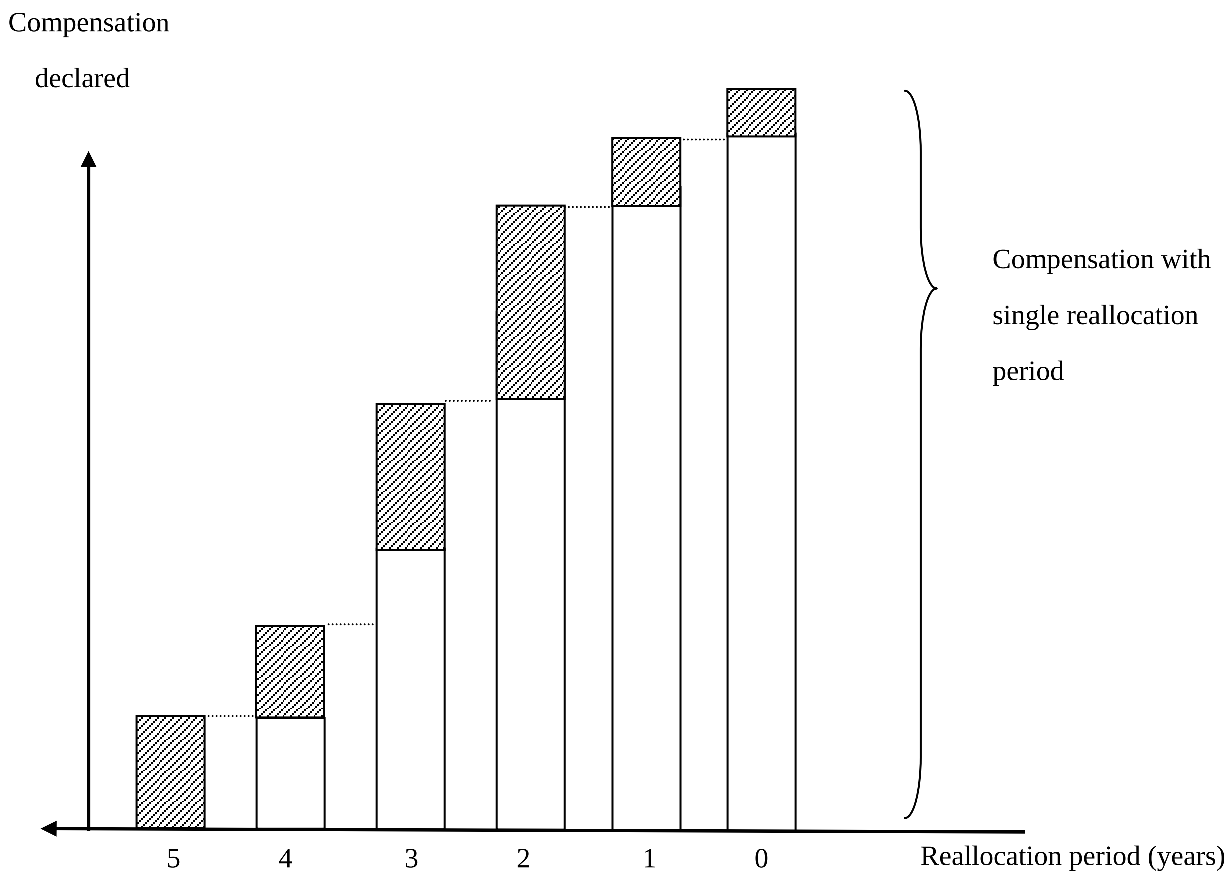

Note :  denotes the increase in compensation when the reallocation period is shortened by 1 year.

Figure 5: Declaration of Compensations with Multiple Reallocation Period

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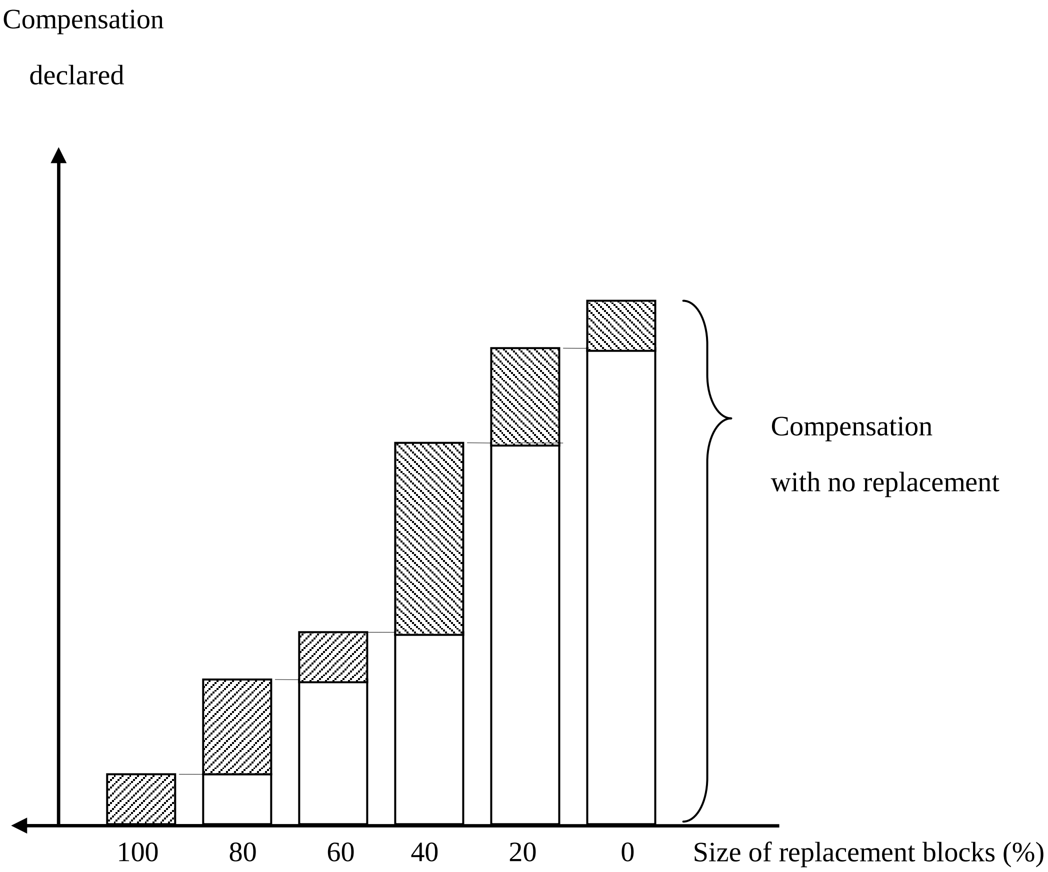

Note :  denotes the increase in compensation when the size of replacement block is decreased by 20% (of the currently-used block).

Figure 6 : Declaration of Compensations with Compensations in Kind (Replacements)

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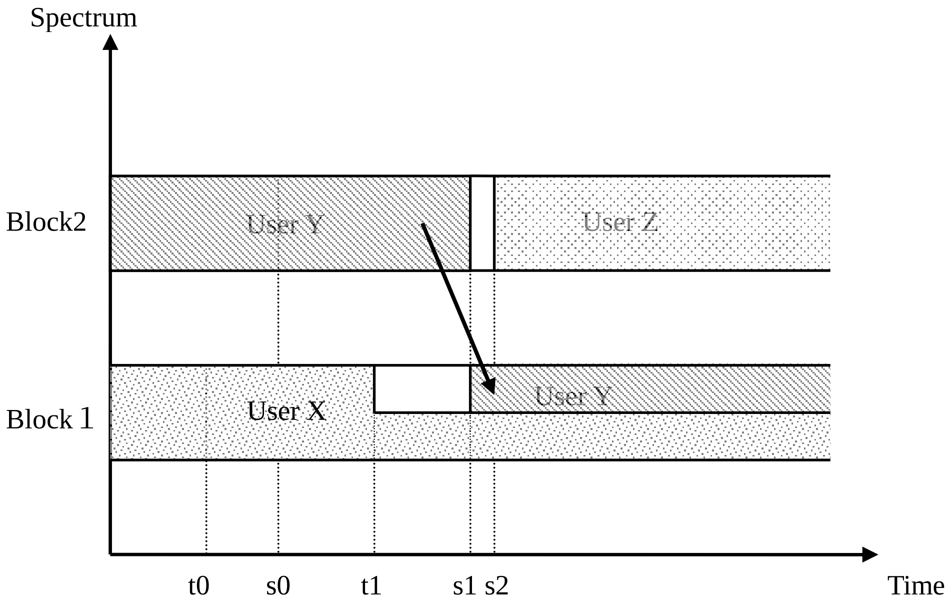

Figure 7: Spectrum Reallocation with Multiple Reallocation Periods and Compensation in Kind

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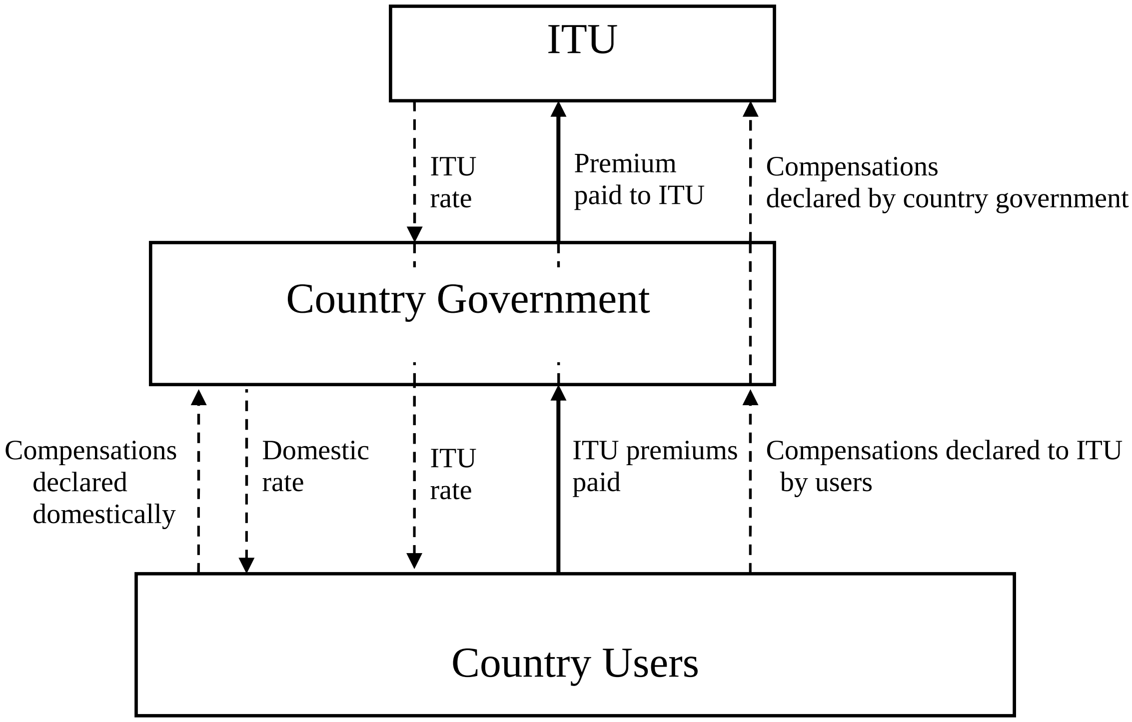

Figure 8(a): International Insurance-Compensations for Reallocation

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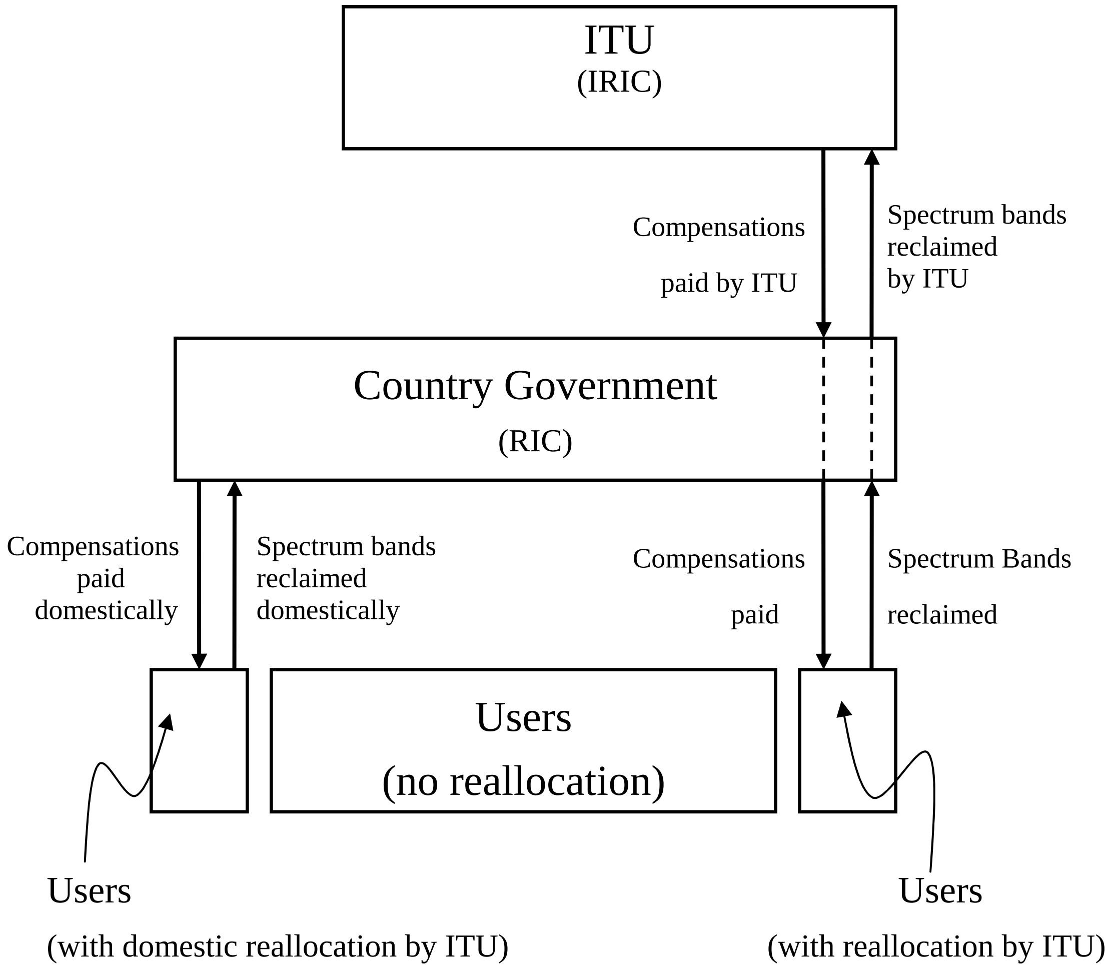

Figure 8(b): International Insurance-Compensations for Reallocation

(after reallocation decision)

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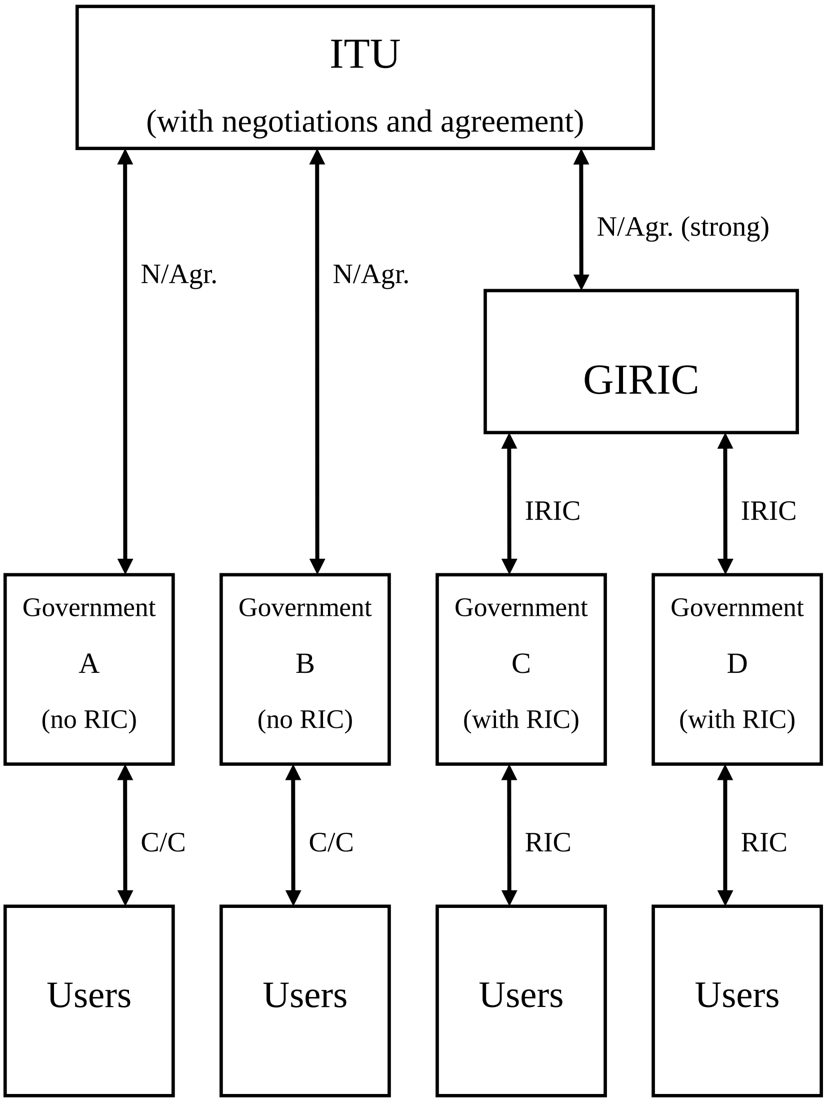

Note: N/Agr. : Negotiations and agreements

C/C : Command and control

Figure 9: International Reallocation of Spectrum with GIRIC

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