(DRAFT) Reallocation of Spectrum Bands with Insurance and Compensation

----Proposal of a New System

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Abstract:

The use of radiowave spectrum is managed in two steps: allocation and assignment (licensing). 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 at international bodies such as ITU.

The objective of this paper is to propose a new mechanism for adjusting allocation, as distinct from assignment, of spectrum by means of insurance, compensation, and supply-price revelation; in short, it is a price mechanism for spectrum reallocation. If implemented successfully, the mechanism can reallocate spectrum in such a way that the spectrum 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 so that their economic state is at least as good as the one before the reallocation. The mechanism can work with various systems for spectrum assignment including command and control, property rights, competitive lease, and commons. It can be used for international reallocation of spectrum as well as for domestic one.

The following summarizes the way in which the proposed mechanism works domestically. (1) Each spectrum user (including government users) is asked to declare an amount of compensation to be paid to the user at the event of reallocation. (2) Each spectrum user pays, say, annually a compensation premium to the government which is equal to the declared amount of compensation

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multiplied by the premium rate to be set by the government. (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 compensation. (5) The government sets the premium rate for compensation so as to balance the total amount of premiums collected from all spectrum users and the total amount of compensations paid to the users of the reallocated spectrum bands. Thus, the mechanism is a fair insurance on spectrum reallocation except at one point: in ordinary casualty insurance (for example, fire insurance), casualty event (fire) for which the insurance is prescribed takes place randomly, while, in this mechanism, "casualty" to a spectrum user is an event of reallocation, an action by the government minimizing the expenditures for compensation. It is noted, that, in this mechanism, each spectrum user has an incentive to reveal the cost of reallocation as an amount of compensation truthfully, since if the user lied to declare it at a level higher than the true cost, the user would have to pay a higher amount of premium on the one hand and the probability of reallocation and compensation would be lower on the other. Thus, the mechanism can prevent "spectrum hold-up." The declared amount of compensation is in fact the price for a user to yield the right of using the band, the supply price of a band with regard to reallocation; the proposed mechanism has the power to have each user reveal the supply price truthfully. It is noted further that the balanced-revenue-expenditure requirement implies that the cost of reallocation is borne by, and distributed among, all spectrum users; such is a desirable arrangement, since spectrum 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 paper describes the operations of this mechanism in detail including the following points: (a) It can work with various assignment systems. With market-oriented systems such as private property and competitive lease, the proposed mechanism will work nicely, since the government and the spectrum users know the value of a band, or of a block, of spectrum better than in other assignment systems. (b) When the proposed mechanism 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 replacement; this is a case of compensation in kind. Such a case can still be managed with the proposed mechanism by introducing contingent compensation; the amount of compensation depends on the size and the location of "replacement block." (c) When a spectrum band is used under commons mode, each user can still declare an amount of compensation; the government can calculate the total amount of compensation for reallocating the band by simply

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summing up all the declared amounts.

In the final section of the paper is considered a way to extend the proposed mechanism to international spectrum allocation conducted by ITU. Roughly speaking, when, on the one hand, a member country allocates spectrum domestically according to the proposed mechanism, it is straightforward to put the preference of the domestic spectrum users through to ITU; the role of the government of the country will be transparent. When, on the other hand, a member country allocates spectrum domestically according to command and control, the government will have to act as an agent representing to ITU the preference of its spectrum users. The paper further discusses a possibility in which member countries with the proposed mechanism implemented domestically form a “club” to express their joint preference on reallocation of spectrum bands in ITU.

I. Introduction and Background

A. Radiowave resources

<physical properties, technological and economic properties>

In this paper, we consider **radiowave spectrum** as an economic resource. Radiowave spectrum covers electro-magnetic waves of which the frequency ranges from 3KHz to 300GHz. We use a portion of radiowave spectrum, called a spectrum band or simply a **band**, for communication by transmitting signals and for other purposes. Needless to say, wireless technology is a crucial means for using spectrum. Thanks to the advancement of wireless technology, radiowave spectrum has become indispensable in our daily life and business.

Let us first summarize the economic 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 peice of land has boundaries and a well-defined size. In fact, both land and spectrum as economic resources can be classified into a category of **space**

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resources, of which examples are land space, water space, air space, the space of satellite orbits, to name a few. The resemblance of spectrum to land is based on 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, the space for having electro-magnetic waves propagate through.[1]

We note that, in order to utilize spectrum, we rely on some technology. Furthermore, for almost all cases, we need to use some devices such as those for wireless communication. The use of land depends also on technologies, and, of course, we need to use some means such as buildings or transportation equipment to derive utility from land space. In short, we need some capital 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 band of spectrum more efficiently such as spread spectrum, software radios, and UWB.

Further, externality is a property commonly possessed by land and spectrum as economic resources. Land exhibits positive externalities in the form of economies of scale area-wise, and similarly spectrum exhibits positive externalities band-wise. Further, both have negative externalities arising from excessive use of a space; they are called congestions for land spaces or interferences for spectrum spaces.

B. History

<beginning of spectrum use, development, current situation>

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 and greatly. In the 1920s, voice radio became popular, and in the 1940s, during the war, radar was invented.

[1] In general, we attach a 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 and 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 used to designate an area on the earth, we add one more dimension for frequencies.

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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 frontier of spectrum utilization. The issue to be dealt with in this paper arises from the fact that such frontier has nearly been exhausted. To be more precise, we should state that there remain many bands unused or rarely used in high frequencies such as 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 VHF and UHF are quite useful to us and the demand for these frequencies exceeds the supply; it does so 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.

C. Management of spectrum

<management bodies, objectives of management>

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

The national level of spectrum allocation is made usually by a 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 for interferences, and the format of modulation and coding needed for information transmission.

The second stage of specifying the use of radio frequencies is the **assignment** of a spectrum **block** to users. Typically, a spectrum band is divided into a number of spectrum blocks, to each of which a single user or multiple users are assigned the right to use it with a license.

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Historically, the main objective of allocation and assignment of radio spectrum 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 technological advances go ahead of spectrum needs, the task of allocation and assignment of spectrum was easy, since the supply of spectrum resources exceeded the demand for them. Once spectrum shortages emerged, however, the situation changed drastically; ITU and national government must now solve a difficult problem how to satisfy the demand for spectrum resources exceeding the given supply. The subject to be dealt with in this paper has become important because of this.

D. Modes and institutions for spectrum assignment

<exclusive use, club use, commons, command and control, property or lease>

In this subsection we consider various **modes** and **institutions** for managing spectrum resources. Much has been debated on this subject during recent years. The objective of this subsection is to give a summary for the discussion in the main sections of this paper.[2]

The first of the modes for spectrum utilization is the **exclusive use**, in which a spectrum block is assigned exclusively to a single user. A license is issued to a user for a limited period of time, and it is usually renewable.

For exclusive utilization of spectrum, we distinguish two institutions; the first is command and control and the second is market mechanism.

Command and control, as widely known, is the traditional system 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 renewable. Typically, there are no rental or lease payments imposed on users except that nominal fees may be charged for 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

[2] For details, see, e.g., Faulhaber [2002], GAO [2003], Hazlett[1998], and Oniki[2002].

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this system, auction may be used for initial assignment and transactions of the right to use a block are allowed. As a consequence, secondary property markets and also secondary lease markets are formed.

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

In comparing market mechanism with command and control as a means to use 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 using spectrum blocks includes **club** and **commons** modes. In both of these, multiple users are assigned to a single block. The difference between club and commons lies in the degree of freedom for new entry. In the club use, new entry may be unlimited or may be restricted by the government. It is customary that a license is issued for club use. Typical examples are amateur wireless communication and wireless communications for 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 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 band for wireless internet access.

Club and commons modes can be realized under command and control or under market mechanism. A typical case at the present time is that ITU and a national government designate a block to be of club or commons use without charging fees, a case of command and control. A club or commons block under market mechanism may be supplied by a public agent. Such an agent would represent 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 must be borne publicly.

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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 widely for the reason that it can promote efficient use of spectrum resources. The other argument insists introduction of commons by emphasizing the advantage of spectrum sharing achieved by recent technological progress. Observe that it is possible for us 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. 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 a national government within the national border. Because of the shortage of useful spectrum bands such as VHF and UHF, new allocation of useful spectrum bands 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 strongly needed objectives such as wireless LAN or RFID. Thus, it is only a dream to open up useful spectrum bands for inviting new inventions yet to be accomplished.

The situation is the same in domestic reallocation of useful spectrum bands. National government, under command and control, attempts to reallocate spectrum bands from incumbent users to new users who can realize more efficient utilization of them. Needless to say, objections from incumbent users are so strong that it takes a long time for the national government to achieve reallocation of useful spectrum bands.[3]

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 compensations.[4]

II. Reallocation with Insurance and Compensation (RIC)

[3] In Japan, the average time period to reallocate spectrum bands for a few cases in the past was ten years or so. For a discussion of the difficulty of spectrum reallocation (relocation), see Cramton [1998].
[4] Ikeda [2003] proposed “reversed auction” for spectrum reallocation, in which the supply price is revealed for some of the spectrum bands. Their system, however, does not carry a provision for insurance program.

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A. Outline

<spectrum users, government>

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

First of all, to incumbent spectrum users, the system RIC is a mandatory insurance with compensations on the event that the spectrum block being used is reclaimed by the government on its reallocation decision. Thus, in this system, each spectrum user (including government and other public users) specifies a monetary amount of **compensation** to be paid to the user by the government on the event that the spectrum block being used is reclaimed and becomes unusable. Each spectrum user pays an insurance premium (compensation **premium**) to the government, 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.[5]

In this system, the government plays the role of an insurance company. First, the government determines a 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 for the spectrum blocks reclaimed for reallocation.

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

B. Selection of spectrum bands to be reallocated

[5] To get an idea about likely magnitude of the premium rate, suppose that we reallocate 10MHz of spectrum annually out of the crowded below-10GHz bands. A simply calculated rate would be 0.1% = 10MHz/10GHz per year.

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<establishing a new allocation, determination of the location of spectrum bands to be reclaimed for reallocation>

Selection of spectrum bands to be reallocated is done by the government in two steps as described below. The first is to establish a new allocation. This depends on technological development and other factors such as standards. In general, when a new way of using spectrum bands is in the vision of the government because of its usefulness and efficiency, the government may determine the size of spectrum bands which will be allocated to the new use. This decision may be done with government 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 government decision would be easier in the latter than in the former.

The second step of reallocation is to locate spectrum bands to be reclaimed from current use and to be reallocated for the new use. Under command and control, as stated previously, this is an extremely difficult decision to the government. Under RIC, however, this decision would be straightforward. The government should choose spectrum bands to be reclaimed so as to minimize the total amount of compensations needed for the reallocation. In doing this, however, the government need to consider matters arising from the presence of positive externalities. Typically, it is desirable to reclaim spectrum bands which are contiguous, or at least located nearby, frequency-wise; the main reason for this is technological conveniences. 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.

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. One of the reasons that such long-run balance is desirable 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 compensations will change from year to year. In some year, there may be a major

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reallocation of spectrum bands; the compensation outlays will be quite high in that year. It is possible that, for several years following the year of a major reallocation, there is little or no reallocation. In such a case, if the annual premium rate is set so as to balance the annual income and outlays of the RIC budget, the rate will fluctuate greatly over years. It is desirable to let users avoid from facing such fluctuating rates for several reasons. One reason for a stable rate is to decrease uncertainty to spectrum users. Another reason is not to give users an incentive to speculate on an amount of compensation.

Thus, the objective for the government to set a premium rate is 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 gradually year by year, not to change it drastically, 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 by government discretions, or by following a pre-determined algorithm (adjustment rules). Consideration of these topics are left for future research.

D. Implications of RIC as an insurance

<fair insurance to spectrum users in the long run, rational behavior of spectrum users>

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 equal 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 reallocation is equal to the level of utility in the case of no reallocation.[6] In other words, with a complete insurance plan, there is no room for users to improve the level of utility regardless whether or not there occurs a casualty.

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

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

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government decision, reallocation of spectrum bands. This discussion is for merely indicating that the system RIC has the property of fair insurance under ideal conditions.

E. Possibility of speculative behavior by users

<spectrum "hold-up">

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-type resource (such as land or spectrum) to attach an extremely high amount of compensation for reallocation in an attempt to acquire extra profits. Holding-up a piece of space-type resource is quite effective when it is located in a strategic position such as in the middle of a large-sized space being reallocated. This is an outcome of positive externalities in using land or spectrum resources; the social cost arising from hold-up maybe very high.

RIC has the power to avoid such spectrum 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 end up 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 some of these in later subsections.

F. Implications of RIC to income distribution

In this subsection, we will discuss an economic implication 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 compensation, whereas the remaining majority of the users pay spectrum premiums and receive nothing. This is the consequence of RIC viewed from the standpoint of income redistribution. In effect, this means that the cost of spectrum reallocation, which is expressed as an amount of compensation, is borne by all spectrum users.

We can say that this is a desirable outcome with regard to income redistribution for the following reason. First of all, the need for spectrum reallocation arises from spectrum shortages, a

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consequence of the use of the whole spectrum by all users. It is not economical, however, to remedy spectrum shortages by trimming off a small piece of spectrum from each user; if we did this, spectrum fragmentation would come out. Therefore, to remedy spectrum shortages, we cannot avoid concentrating spectrum resouuce to be reclaimed into 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 spectrum is in a sense a sacrifice for all spectrum users. Compensating this user with the income collected from all users can be justified on this ground.

III. RIC and Spectrum Assignment

A. Club or commons

<club or commons users, government action>

In this section, we examine the functioning of RIC when it is associated with alternative systems for spectrum assignment. First, we summarize 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 opened 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.

When RIC is implemented, club or commons users accept that the block may be reclaimed for reallocation. Each user can declare an amount of compensation which will be paid in the event of reallocation. In practice, it may be convenient for club or commons users to pay insurance premiums at the time they purchase devices for using the frequencies in the block. For example, users of an electro-magnetic heater may wish to pay in one installment the compensation premiums for a period of expected duration of the equipment (e.g., for 10 years).

Thus, 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.

It is noted that, when a club or commons block is supplied to final users not by the government but by a public or private agent (e.g., by wireless internet access providers servicing to internet subscribers or by wireless telephone operators servicing wireless telephone users), RIC

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induces spectrum users such as operators to develop a RIC-like arrangement (contract) with customers (internet or potable telephone subscribers). Then, the amount of compensation to be paid by an operator to customers in the event of reallocation should be the sum of the compensations claimed by all customers. Therefore, the amount of compensations that an operator should declare in the event that the block is reallocated is the sum of the compensations to be paid to all customers for terminating the service[7].

Thus, we can state that RIC works well with club or commons assignment.

B. Market mechanism

<spectrum users, government>

When spectrum is assigned under a market mechanism, RIC will work very well. The government allocates a band for exclusive use for specific objectives and with technological restrictions. 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. 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 bands, then the government should plan 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 works well when spectrum assignment is under market mechanism, which can provide the value of spectrum in the form of prices.

[7] Note that the consequence of reallocation need not be limited to a termination of the service; a RIC-like arrangement such as a transfer to another block is conceivable.

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C. Command and control

<spectrum users, government>

When spectrum assignment is made under command and control by a government, RIC still works, but not so well as in the case in which assignment is made under market mechanism. In command and control, the government assigns spectrum blocks to users on the first-come base, comparative hearings, or random selection. 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, need to calculate an amount of compensation with a great deal of uncertainty. In particular, they may need to guess the intention of the government with regard to assignment of spectrum blocks. If a user is given a replacement block by the government after reallocation, then the amount of compensation will be the cost of switching from the current block to the replacement block. If a user is not given such a replacement block after reallocation but the business can be continued by some other means (e.g. by using optical fibers to replace wireless communication), the amount of compensation will be the switching cost from wireless to fibers. If the business cannot be continued without using spectrum, then the compensation should include the cost arising from terminating the business.

When spectrum assignment is made under command and control, the government cannot use price data in making decisions on reallocation; without RIC, the government may need to collect data expressing the value of spectrum in some way. 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 in the opposition by incumbent users. In contrast to this, RIC can help the government find spectrum bands needed for reallocation. Note, however, that RIC does not provide the government with information where spectrum bands should be reallocated to.

IV. Discussions of RIC

A. Economic meaning of compensations

As stated previously, RIC is an insurance system to spectrum users; it covers the risk of

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reallocation. RIC, however, is more than an insurance system, since the event of spectrum reallocation is an outcome of the government decision minimizing the total amount of compensations payment, i.e., selecting those users declaring relatively a low amount of compensations; spectrum reallocation is not an outcome of unpredictable random event such as fire or earthquakes.

With proper incentives, of which details are discussed below, spectrum users tend to declare an amount of compensation in the event of reallocation to be equal to the least amount of money that they can accept as compensation. This means that, in effect, the amount of compensations declared by spectrum users tends to be the **supply price** of spectrum resources with regard to reallocation. This is the reason that we say RIC is a price mechanism as well as an insurance program. Thus, RIC is a mechanism to calculate the value of spectrum resources in the same way that an ordinary price mechanism works as a means to calculate the value of the good. In short, RIC is useful to the society for the same reason that the price mechanism in general is useful to it.[8]

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

<criteria for reallocation, market mechanism, command and control>

In this and the following subsections, we will consider the behavior of the government with regard to making decisions on reallocation. We first deal with the question whether a particular spectrum band should or should not be reallocated for a new objective of use.

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, a band should be reallocated only if the efficiency-improvement index is greater than 1, where

(the efficiency-improvement index) = (B – C) / A,

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

[8] 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 used for trade. 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 or supply prices, since buyers or sellers need not express them to conduct transactions. In RIC, however, the supply prices need to be 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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B = (the present value of the band with a new use),

C = (the compensations to be paid for reallocating the band).

In practice, a practical way for reallocation decision may be something like the following. First, the government forms 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 index. 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 set of spectrum bands currently in use with efficiency-improvement indices greater than one. That is to say, to each new objective is attached a set 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. The process described above may 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.

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, although the government still needs to estimate the expected rate of return from using a band for a new objective. In doing such estimation, some discretionary decision making is unavoidable. 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 needs 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 of decision making for reallocating spectrum is greater in the case of command and control than in the case of market mechanism.

C. Decision by government on the selection of spectrum bands to be reallocated (reclaimed)

<selection of bands to be reallocated, prevention of speculative behavior by users>

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In general, selection of spectrum bands to be reclaimed for reallocation should be done 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 news in such a way that the bands are located contiguously or within a relatively narrow range of frequencies. But this could invite speculations and manipulations by spectrum users in declaring an amount of compensations.

A typical case for a spectrum user to declare an amount of compensation speculatively for making extra profits may be something like the following. Such 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.

To avoid such speculations and 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. Revisions to increase the amount, however, should be done slowly and gradually; a sudden and abrupt increase in the amount of compensation should be regulated. There seems to be no reason to regulate downward revisions, though. Further, the government should disclose all information about the amount of compensations declared and give ample time for users to revise their declarations. In this way, a speculative declaration will be eliminated gradually through competition among spectrum users. It is for future research to devise an exact algorithm for the government to follow for this.

D. Determination of the amount of compensation by users

<non-speculative decision>

In this subsection, we consider the behavior of non-speculative profit-maximizing users of spectrum in determining the amount of compensations to be paid in the event of reallocation. We assume that speculative declaration does not arise because of government regulations and

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competition among users. Then, the amount of compensation declared will be the minimum amount of money that a user is willing to yield the right for using a spectrum block. Roughly speaking, this amount will be determined according to the following equation;

(the amount of compensation to be declared)

= (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. 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. The amount of compensation to be declared, therefore, will be the minimum of the right-hand side of the equation, where minimization is taken over all possibilities of new business, including no new business, after reallocation. Thus, the amount of compensation to be declared by a spectrum user is the supply price of a spectrum block with regard to reallocation.

E. Introduction of multiple reallocation periods

<reallocation period, an example of RIC with five 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). 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 allowed ten years or so in average for reallocation period. In general, the cost of reallocation, to be revealed in the amount of compensation in RIC, may greatly depend on the reallocation period. It is advantageous both for 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 an example of a RIC with multiple reallocation periods.

Let us consider, as am example, a case in which there are five different reallocation periods;

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one-year period, two-year period, …, five-year period. Spectrum users are to declare an amount of compensation for each of the five reallocation periods and pay a premium for each of them. It is expected that, since, when reallocation is executed, only one out of five reallocation periods is chosen, the average premium rate for each compensation period declared is approximately one-fifth of the rate in the case of single reallocation period.

Thus, spectrum users exhibit their preference over five different reallocation periods by means of an amount of compensation attached to each reallocation period. If it is convenient for a spectrum user to have, say, three-year reallocation period in the event of reallocation (for the reason that, say, the average depreciation period of the devices in use is three years), the amount of compensation attached to the three-year period will be far less than the compensations attached to the remaining four reallocation periods.

The principle according to which the government sets premium rates in this system is still the long-run balance of the RIC budget. It is possible to have a single premium rate to be applied uniformly to the five reallocation periods. It is also possible to set a premium rate to each of the five reallocation periods separately. For the latter case, the algorithm according to which the government sets premium rates will be somewhat more complicated than in the single-rate case or in the case of a single reallocation period. Considering an appropriate algorithm for the government to do this is a subject for research in the future.

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 of decisions (i.e., announcements) to be revised each year. That is to say, in each year, the government selects spectrum blocks to be reclaimed in each of the five years to come. The principle of minimizing the total amount of payments for reallocation executed should be observed for each year.

F. Introduction of (partial) compensation in kind

<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. The government used this type of compensation for reallocating spectrum in the past. It was useful during the period in which the frontier of spectrum resources

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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 may be able to find replacement spectrum blocks without much difficulty (e.g., in high-frequency bands).

In order to explain, let

X = (the size of spectrum block assigned to a user before reallocation)

Y = (the size of spectrum block assigned to the user as compensation in kind),

where it is understood that $Y \leqq X$.

In this system, spectrum users still declare a full amount of compensation, i.e., an amount which is to be paid in the event of reallocation without replacement. Whether or not to provide users with replacement spectrum blocks is a decision to be made by the government, and, if the government decides to do so, spectrum users of which their blocks are reclaimed will have an additional choice of how much to accept the replacement offer made by the government.

One way to realize such a system follows. First of all, the government specifies an upper bound $\overline{Y}$ ($\leqq X$) of compensation in kind Y. Then user can choose a Y ($\leq \overline{Y}$) and receive an amount of monetary compensation calculated according to the following equation;

(the amount of monetary compensation to be received by a user accepting a replacement block Y)

= (the declared compensation for X) * ($X - Y$) / X.

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 operations 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 the use of spectrum resources.

V. RIC for International Reallocation of Spectrum (IRIC)

A. International reallocation of spectrum

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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 benefit in spectrum reallocation as RIC gives a country.

At the present time as well as in the past, international allocation and reallocation of spectrum resources is governed by international organizations such as International Telecommunication Union (ITU). Decisions in ITU are made mainly on negotiations by member countries. Because of 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 which are 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 governments have. 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

<government of member countries, ITU>

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 a national government played in RIC for domestic reallocation will be played by ITU for international reallocation. The role of users played in RIC for domestic reallocation will be played by member countries in IRIC for international reallocation.

Thus, a member country specifies an amount of compensation for each spectrum band in the event 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 achieve the long-run balance of the IRIC budget.

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

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This may still be done on negotiations, although it is expected that, with IRIC, member countries can use for making reallocation decisions 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.

Thus, the way that IRIC works is almost identical to the one that 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 as there are inter-user transfer of income under domestic RIC. Observe that, in any international reallocation of spectrum bands, we cannot avoid that some countries are benefited and some other countries receive 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)

<ITU with IRIC, member countries with RIC>

In the remainder of this section, we deal with 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, a 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 domestic government distributes the compensation payments received from ITU for reallocated bands to domestic users according to the amount declared by 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 which would arise in the case in which domestic users dealt directly with ITU (without intermediation by a national government).

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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.

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

<ITU with IRIC, member countries without RIC>

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 a national government.

First, the national government, a member of ITU, follows 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 amount of work to be done by the national government for doing this is of the same order as in the amount of 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; thus the net amount that the domestic government receives or needs to finance may not be a burden to it.

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

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<ITU without IRIC, member countries with RIC>

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 a 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 member countries with domestic RIC to form a group within ITU for spectrum reallocation. We call it the group of countries for IRIC (**GIRIC**). The GIRIC member countries may execute IRIC within GIRIC; it is like forming a Free Trade Agreement (FTA) by a number of countries 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 a 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 or compensation payments for spectrum reallocation. The outcome of such a simulated IRIC within GIRIC may be used to form an opinion by the GIRIC member countries for negotiations in ITU. The possibility that an allocation 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 mechanism to collect information about the value of their domestic spectrum bands, and then to aggregate such information into the one common to the GIRIC member countries. This is an example of the informational benefit of RIC and IRIC as a price mechanism.

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Figure II. 1 : Insurance-Compensation for Reallocation

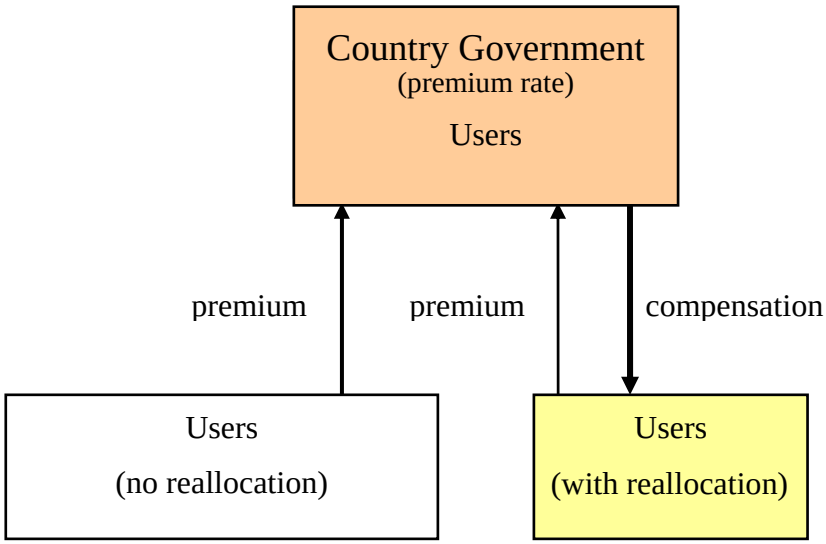

Figure II. 2 : International Insurance-Compensation for Re-Allocation