Facilitating Spectrum Management Reform via Callable/Interruptible Spectrum

by

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Abstract

The desire of service providers to offer "third generation" (3G) wireless services and applications has focused renewed attention on the manner in which public sector spectrum is employed. This paper provides an analysis of the public sector spectrum management system and demonstrates that it currently creates strong incentives for public sector spectrum users to misrepresent their spectrum needs. The paper shows that granting public sector users the ability to trade their spectrum assignments will improve the allocation of spectrum and, moreover, will promote its efficient use. The paper also discusses several factors that may reduce the willingness of public sector spectrum users to fully participate in a spectrum market. One such factor is "performance risk," herein defined as the risk that a stochastic event will render a prior spectrum sale or lease highly problematic. The paper proposes a simple method by which risk can be efficiently transferred from the public sector user to either the leasee or acquirer of the spectrum. It involves permitting market participants to exchange "preemptable" or "callable" spectrum. Under preemptable spectrum a buyer assigns to the seller the right to preempt or call back its leased or sold spectrum in the event of some stochastic event. The price at which the seller is willing to release its spectrum to another user will depend upon the seller's confidence that it will have access to the spectrum when it exercises its preemption right. Such confidence can be provided through the use of a beacon system that is controlled by the seller. Under this system, the leasee or acquirer could only use the spectrum if it receives a beacon signifying that access is permitted. The paper proposes that the spectrum market be organized as an "electronic call market." It then presents a simply method by which participants can trade spectrum on a callable basis within such a market institution.

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A. INTRODUCTION

The Federal Communications Commission ("FCC") and the National Telecommunications and Information Administration ("NTIA") have adopted spectrum management procedures designed to promote the effective and efficient use of this resource. To satisfy this objective, NTIA (on behalf of Federal Government spectrum users) and FCC (on behalf of state or local government spectrum users) evaluate the long-term spectrum needs of different public sector users, identifies different strategies for satisfying such needs, and implements the plan that is most likely to achieve the stated objective. The solution is implemented through administrative procedures that allocate spectrum to specific uses and assign spectrum to competing public sector users.1/

Some argue that current public sector spectrum management practices cause some users to employ too much spectrum in providing their valuable public services, resulting in a misallocation of spectrum between public sector and private sector users.2/ To date, NTIA and FCC have addressed such criticisms by redoubling their efforts, largely administrative in nature, to ensure that spectrum is managed consistent with the above objective. This paper addresses these criticisms by proposing a market-based approach for managing public sector spectrum that involves granting incumbent public sector spectrum users the right to trade their spectrum assignments to either public sector or private sector spectrum users.3 Price signals rather than government fiat, should determine not only the type of spectrum that is re-allocated to commercial users, but also the timing of such a re-allocation. Because all trades are voluntary, both the buyer and the seller are, by definition, better off following the trade.

The employment of a market mechanism to allocate spectrum between public sector and commercial users will expose public sector spectrum users to the risk that a stochastic event (i.e.,

1 The word "allocation" has multiple meanings. Economists use the word to describe a given distribution of resources among users. Spectrum analysts and engineers use it to describe the administrative process of dispensing spectrum to specific uses. The reader should adopt the former meaning throughout the paper.
2 Senator Pressler once recommended that a Congressional Commission identify and reallocate between 20% and 25% of the Federal Government spectrum to the private sector.
3 NTIA recognizes the possibility that market based forces may be used to guide the spectrum management process. See, for instance, High Frequency (3-30 MHz) Spectrum Planning, Office of Spectrum Management, NTIA Special Publication 96-332, (1996), pg. 1-5.

an emergency or technological change) will render a prior spectrum sale or lease highly problematic. One method by which the public sector user can efficiently shed this risk is through the exercise of a "preemption right." Such a right would enable the public sector spectrum user to preempt the buyer's right to use the spectrum in the event of an emergency or some other stochastic event. The price at which the public sector spectrum user is willing to release its spectrum to another user will depend upon the seller's confidence that it will have access to the spectrum when it exercises its preemption right. Such confidence can be provided through the use of a beacon system that is controlled by the seller. Under this system, the leasee or acquirer could only use the spectrum if it receives a beacon signifying that access is permitted. Finally, the efficient assignment of this right requires that it is correctly "priced." The price of such a right can be established through the use of an electronic call market.

The paper is organized in the following fashion. Section B defines the phrases "allocative" and "technical" efficiency and presents an economic analysis of the existing public sector spectrum management system. Section C describes two methods for improving the way in which spectrum is allocated across competing users. Section D describes important impediments to the efficient reallocation of spectrum, including the risk that public sector users face when releasing spectrum to other users. One solution is to provide public sector spectrum users the opportunity to trade "callable spectrum." Section E discusses the use of an electronic call market for facilitating spectrum trades between buyers and sellers. Finally, Section F presents some conclusions.

B. MANAGING RADIO SPECTRUM: AN ECONOMIC PERSPECTIVE

Economics involves the study of how best to satisfy society's wants as determined by the preferences of economic agents (e.g., spectrum users, movie studios, households). However, because the demand for most resources exceeds their supply when offered at zero price (e.g., radio spectrum, Luciano Pavarotti, government bureaucrats), and because individuals appear to desire more of a resource than less, the welfare of all individuals can not be maximized. Indeed, increasing one individual's welfare typically means providing less resources to another. The phrase "allocative efficiency" refers to the degree to which a given resource allocation maximizes the value society places on those resources, given the required tradeoffs.

The concept of allocative efficiency can be described through a simple example. Suppose there are two entities, Verizon and the Department of Defense ("DoD"), each of which wishes to use one of two spectrum licenses, License A and License B. Table 1 below presents the valuations each entity places on the licenses, where "value" represents the discounted present value of the stream of benefits each entity receives from using the license.4/

SPECTRUM ALLOCATION PROBLEM (Example – Two Licenses, Unit Demand)		
Entities	License A	License B
Verizon	100	99*
DoD	95*	89

Table 1

Allocative efficiency would be maximized if Verizon received License B and DoD received license A. Such an allocation maximizes the value society places on the available licenses, as measured by the value each entity places on them. There is no other allocation of Licenses A and B that would generate more value to society. If, by chance, License B was allocated to DoD and License A to Verizon, society's welfare would be enhanced if Verizon and DoD swapped their respective licenses. Importantly, the increase in society's welfare is obtained without an increase in the number of licenses available.5/

A. Allocating Spectrum Among Users: Incentives For Misrepresentation

From an economic perspective, the spectrum manager's problem involves assigning a

4 For Verizon, these benefits are measured by the revenue it would obtain from using the license. For DoD, these benefits are measured by the improved combat capability of its military service units.
5 The optimality of any resource allocation requires that the respective valuations be based upon competitive prices.

fixed amount of spectrum to competing users such that the benefits society receives from its use are maximized. This task would be greatly simplified if the spectrum manager knew the "true" relationship between society's well-being and public sector spectrum use.6/ Unfortunately, identifying this relationship is complicated by two factors. First, because many public sector spectrum users provide services for which they receive no direct monetary payment from beneficiaries (e.g., air traffic control service provided to airline passengers), it is difficult to place a monetary value on the benefits society obtains from their services.7/ Second, public sector users have an incentive to misrepresent their spectrum needs and requirements. The latter problem can be demonstrated through a simple example.

Suppose the radio spectrum consists of only two bands, x_1 and x_2, each of which contain 10 separate frequencies.8/ Suppose, further, that there are only two potential users of these bands, the Army and Navy and, moreover, that the value to each user -- measured in terms of combat capability -- is positively related to the amount of resources assigned to each user.9/ Suppose the "true" relationship between spectrum use and combat capability for the two users are $Q_{Army} = 10\ x_{1Army} + x_{2Army}$ and $Q_{Navy} = x_{1Navy} + 10\ x_{2Navy}$, and that each relationship is known only to the respective users.10 Finally, suppose that the spectrum manager must allocate spectrum in such a way that equalizes the combat capability of both the Army and Navy.

Given its objective, the spectrum manager should implement the spectrum allocation $X = (((10,0)_{Army}, (0,10)_{Navy}))$.11/ This allocation is the economically efficient allocation in that it

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If this condition is not satisfied, resources will not be optimally allocated.

6 The spectrum manager's spectrum allocation problem would reduce to an integer programming problem if he possessed this information.

7 In a market economy, revenues are sometimes used as a first approximation in measuring the societal benefits from a given service or product. The absence of this first approximation doesn't necessarily mean that prices shouldn't be used to allocate spectrum between public and commercial uses.

8 The allocation problem presented here is similar to the problem management faces when allocating resources for a research project among competing users. See Ledyard, J., Porter, D., and Rangel, Antonio, "Using Computerized Exchange Systems to Solve An Allocation Problem in Project Management," *Journal of Organizational Computing*, Vol. 4, No. 3, (1994) (Computerized Exchange Systems).

9 We make the unavoidable assumption that society's well-being is positively related to the Army and Navy's combat capability.

10 These relationships can be viewed as the payoffs to the Army and Navy and, therefore, to society associated with different allocations of spectrum. In practice, both the Army and the Navy may be uncertain about the level of their respective payoffs.

11 The parameters (i.e., 10, 1) in these two equations represent the contributions an additional unit of spectrum (i.e., x_1 and x_2) will make in increasing the user's combat capability. According to the parameter values, an additional unit of x allocated to the Army contributes more to the nation's aggregate combat capability than if it was allocated

maximizes total combat capability (i.e., 200), subject to the constraint that both users' combat capability are equalized. However, believing that more spectrum is better than less, the Army would not be satisfied with its spectrum allocation. The Army could increase its allocation if it could convince the spectrum manager that the true relationship between its capability and spectrum use is $Q_{Army} = 5\, x_{1Army} + x_{2Army.}$ Given this relationship, combined with its objective of maximizing total combat capability subject to the constraint that both users' combat capability are equalized, the spectrum manager would implement the allocation $Y = (((10, 50/11)_{Army}, (0, 60/11)_{Navy}))$. This new allocation provides the Army with additional spectrum (i.e., 50/11 units of x_2). Therefore, by understating the true relationship between its combat capability and spectrum use, the Army has enhanced its spectrum allocation position.

The example assumes that only the Army misrepresents the contribution spectrum makes in helping it achieve its objective (i.e., combat capability). However, because of the positive value public sector users place on additional spectrum, both the Army and the Navy will have an incentive to understate the true relationship between spectrum use and their ability to satisfy their respective missions.12/ In practice, the incentives created by the existing spectrum management system will induce many, if not all, public sector agencies to misrepresent their spectrum needs and requirements, thereby further complicating the spectrum manager's problem.13/

The incentives public sector users have to misrepresent their spectrum needs will also harm society's economic welfare. To see this, consider the two spectrum allocations discussed in the previous example. Under spectrum allocation $X = (((10, 0)_{Army}, (0, 10)_{Navy}))$, combat

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to the Navy. The opposite is true for x_2. Moreover, because this example assumes, for simplicity purposes, that these parameters do not change with increases in the amount of spectrum allocated (i.e., are not subject to the "law of diminishing marginal returns"), x_1 will always have a higher level of productivity if allocated to the Army, while x_2 will always be more productive if allocated to the Navy. Therefore, the optimum involves allocating all of x_1 to the Army and all of x_2 to the Navy.

12 Misrepresentation derives from the public sector spectrum user's interest in promoting its interest. The desire of a public sector user to promote its interest should also exist if a market-based mechanism is employed to reallocate spectrum from public sector to commercial use, or vice versa.

13 Some criticize current spectrum management policies because, unlike decentralized (i.e., market based) approaches, an administrative approach can not properly adjust to changes in technology and the preferences of consumers and producers. More formally, they argue that market participants possess "private information" that, for one reason or another, either never gets transmitted to the spectrum manager or is transmitted too late. This analysis indicates that the spectrum manager's problem is significantly more complicated. It states that spectrum users have an incentive to misrepresent the information they provide the spectrum manager.

capability reached 200, while the allocation $Y = (((10, 50/11)_{Army}, (0, 60/11)_{Navy}))$ yields a combat capability level of only 109.09. Therefore, a reallocation would lead to a net increase in the Army and Navy's combined combat capability. Importantly, this increase occurs without an increase in the supply of spectrum devoted to the armed services.14/ To reach the efficient allocation, public sector spectrum managers would have to, under current procedures, confiscate the inefficiently-held spectrum from the Army and transfer it to the Navy.

B. Economic Efficiency And Spectrum Use

Under current regulatory practices, even if the public sector agency that values spectrum the most receives it, it doesn't necessarily mean that it will be efficiently used. The economically efficient use of spectrum requires that the agency, first, identify the "technically efficient" method of transforming all of its scarce resources into services. "Technically efficient" resource combinations are those that produce a given output level with the minimum physical quantity of each resource. If, for example, a VHF Air Traffic Control System requires 1 AM channel, with a bandwidth of 25 kHz, per message, then the use of 1 AM channel with a bandwidth of 50 kHz cannot be a technically efficient way of providing such service. Second, given the technically efficient resource combinations, the public sector agencies must identify the least cost resource combination for any given level of service output, given the cost of each resource.15/

The resource combination that minimizes the cost of producing a given level of output requires that the increase in output due to the use of an extra unit of a given resource (i.e., resource's "marginal product"), divided by its price, be equal for all resources employed. In a market economy, any deviation from the cost minimizing resource mix will induce a firm to alter its mix -- using more of some, less of others -- until the marginal product/price ratio is equal

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14 The decrease in combat capability is a direct consequence of the parameter values in the equations. These values represent the contributions an additional unit of spectrum will make in increasing each user's combat capability. According to these parameters, an additional unit of band x_2 contributes 10 units to the Navy's combat capability, while contributing only one unit to the Army's combat capability. Because of this fixed difference in the incremental contribution between the two users, combined combat capability would be maximized if all units of x_1 are allocated to the Army, and all units of x_2 are allocated to the Navy. Any deviation from this allocation will lead to a reduction in aggregate combat capability.

15 Finally, taking into account the benefits society obtains and the cost it incurs, some entity must identify that level of service output that maximizes society's welfare. Typically, this decision is made by Congress through the budget authorization process.

across all resources employed.16 Indeed, any deviation from this resource combination necessarily implies a waste of society's scarce resources in the case of a public sector agency, or reduced profits in the case of a firm.

Public sector spectrum users face a number of impediments in reaching a cost minimizing resource mix. For instance, obtaining this optimal mix requires that the resource user face the "correct" price -- a cost from the purchaser's perspective -- from using one more increment of each resource. The relevant price is not the price the user paid to acquire the spectrum initially, but rather the benefits the user foregoes (i.e., an opportunity cost) by using spectrum in its current use versus its next "best" use. To take a practical example, a family's true cost of constructing an addition to their house is not the out-of-pocket cost associated with constructing the addition, but rather the foregone benefits associated with placing the money it its next best use, which may include purchasing a new car or taking a trip to northern Italy.

With this in mind, a public sector spectrum user's cost of "using" employing spectrum is not what it initially paid for spectrum (i.e. zero), but rather the foregone benefits associated with what the user could obtain in an exchange with a firm that wishes to obtain its spectrum assignment. A public sector user will be induced to "waste" spectrum, therefore, if it faces an artificially low opportunity cost associated with using its spectrum.17/ The opportunity cost that a public sector user faces by retaining its spectrum assignment is determined by the spectrum's highest valued alternative use which, in turn, is determined by the range of services that it could provide and the collection of users (e.g., public sector, non-public sector) that are permitted to provide those services.18/

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16 The condition states that a service provider must, in order to provide a given level of output at least cost, combine its resources in such a way that the marginal physical product per dollar's worth of one resource is equal to the marginal physical product per dollar's worth of every other resource used. This means that the last dollar outlay on one resource adds the same amount to total output as the last dollar outlay on any other resource. If this equality condition does not hold, the resource user can not be allocating its resource expenditures in a manner that maximizes its output given its financial budget. The user can maximize its output by using more of some resources and less of others. Because of the "law of diminishing returns," these changes will alter the resources' marginal physical product and, in so doing, enable the user to satisfy the equality condition, even in instances where the prices of the respective resources remain constant.

17 Because the demand for the services of public sector spectrum users are sometimes uncertain (i.e., stochastic) and because their services are largely non-storable, they sometime possess excess spectrum. Public sector spectrum users face the same opportunity cost whether the spectrum is being "used" or whether it is being held in reserve.

18 This first factor raises the issue of flexible use. For a discussion of the economics of flexible spectrum use, see Bykowsky, Mark (1997) "Allocating Spectrum Through Market Forces: Spectrum Use Flexibility," Unpublished

Public sector users will face the correct opportunity cost (i.e., the opportunity cost that directs resources to their highest valued use) if the second highest valued user is free to use such spectrum. If this option is not available to such a user, current users will face an artificially low opportunity cost associated with using their spectrum and, therefore, will not have the correct incentives regarding how best to combine spectrum with their other resources. More precisely, this low opportunity cost will induce public sector users to use, or to hold in reserve without use, "too much" spectrum, relative to the cost minimizing mix, in providing their required services.19

C. SOLVING THE SPECTRUM ALLOCATION PROBLEM

The public sector spectrum manager's current job is a very difficult one. To find the economically efficient allocation of spectrum, the spectrum manager must have information regarding the value each user places on different spectrum bands across geographic space and time. In the previous example, to efficiently allocate spectrum, the spectrum manager must know the true relationship between combat capability and spectrum use for both the Navy and the Army. If this information is known, procedures exist that would quickly identify an efficient allocation of spectrum between these two users. However, to the extent that they place a positive value on additional spectrum and that they are unknown to the spectrum managers, public sector users have an incentive to misrepresent the value they place on additional spectrum.20/

There are two alternative approaches to solving the public sector manager's spectrum allocation problem. The first method involves using a centralized administrative process that alters a user's expected payoff associated with strategically misrepresenting its spectrum needs and requirements. The second method consists of permitting spectrum users to trade their assignments and, in some instances, their allocations. The following discusses these two alternative approaches.

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19 This does not mean that Public sector spectrum users intentionally "waste" spectrum. Rather, these users are behaving optimally given the economic incentives generated by the existing spectrum management system.

20 Because the incentive to misrepresent one's valuation exists regardless of the strategies adopted by the other public sector agencies, misrepresentation represents a "dominant strategy."

A. Administrative Processes: Learning and Penalties

One method of "solving" the spectrum manager's allocation problem is to reduce users' expected payoffs from exaggerating the value they place on spectrum. This requires that the spectrum manager obtain information regarding public sector users true spectrum needs and impose a penalty on egregious misrepresentations. One drawback from this approach is that the information the spectrum manager needs may be either impossible to acquire or very costly to obtain.21/ Alternatively, there may be legitimate public interest reasons (e.g., national security considerations) that require that some sensitive information remain confidential. Moreover, the size of the imposed penalty should be equal to the cost the value misrepresentation imposes upon society. Identifying this cost may be very hard given the difficulty of determining the "true" value that users place on spectrum.

B. Market Process: Voluntary Spectrum Trading

Approaching the spectrum manager's problem in a slightly different manner reveals a different solution to the spectrum manager's problem. The approach begins with the assumption that the spectrum user will always have, for all practical purposes, much better information than the spectrum manager regarding the value it places on spectrum. As a result, the spectrum manager may be more successful at reaching an efficient allocation of spectrum if it enlisted the help of prospective spectrum users. The help is obtained by altering the incentive structure in such a way that the spectrum user's self-interest is compatible with the interest of the spectrum manager. Specifically, solving the spectrum manager's allocation problem requires that spectrum users be motivated, through the use of incentives, to behave in a manner that will lead to an efficient allocation of spectrum.

One method of motivating current spectrum users to behave in a manner consistent with society's interests involves assigning spectrum to prospective users and permitting them to engage in voluntary trades. A trading mechanism is based on the notion that two parties will engage in an exchange only if they are both better off after the exchange. Moreover, absent harmful effects to a wider group of parties as a result of the trade, such trading will promote

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21 In the extreme, eliminating all incentives users have to misrepresent their spectrum needs by monitoring spectrum use may actually harm economic welfare if the cost of monitoring exceeds the gains from a more efficient allocation of spectrum.

society's interests as well. We can show this by revisiting Table 1, reprinted below for purposes of convenience.

EFFICIENT ALLOCATION (Example – Two Licenses, Unit Demand)		
Entities	License A	License B
Verizon	100	99*
DoD	95*	89

Table 2

As you may recall, the economically efficient allocation has License A being assigned to DoD and License B being assigned to Verizon. For the moment, suppose that Verizon has License A and DoD has License B. To determine whether such firms have an incentive to trade their respective licenses, consider the potential benefits to each entity from participating in such a trade. For Verizon such a trade would decrease its welfare by 1 unit (i.e., 100 - 99) while DoD would have its welfare increased by 6 units (i.e., 95 - 89). Therefore, in order for the trade to occur DoD would have to provide Verizon at least one unit of value in order to induce it to accept the trade. DoD would have the incentive to do so given that it would improve its welfare compared to the existing allocation. Importantly, such a trade would not only enhance the respective welfares of both parties, but it would also lead to an economically efficient allocation. In general, a voluntary exchange between two parties can only enhance efficiency in the allocation of resources.22/

All things being equal, once an efficient allocation of resources has been obtained no user has an incentive to change its resource allocation. It follows, therefore, that a resource trade will only occur if resources have been inefficiently allocated among users or if the valuations that

22 The existence of negative "externalities" causes a divergence between the trade's private and societal benefits. Consequently, because trades are based on private returns, some trades may occur that diminish society's well being. Indeed, the presence of negative externalities, combined with the inability of private negotiations between the participating parties to resolve the "externality problem," serve as the primary basis for government involvement in

prospective users place on spectrum have increased since the initial allocation. If the process of finding mutually beneficial exchange is not obstructed by high transaction costs (e.g., buyer/seller identification, marketing expenditures, expenditures to reduce "informational asymmetries"), users will voluntarily execute a series of trades that will lead to an efficient allocation of resources (e.g., radio spectrum).23/

D. TRADE IMPEDIMENTS

Several impediments exist that may dampen the willingness of government users to participate in a secondary market for the trading of spectrum.24/ For example, public sector agencies receive funding through an appropriations process. A public sector agency may believe that its funding level would be reduced if it received revenue from a spectrum trade. Such a belief may substantially reduce the agency's incentive to complete the spectrum trade. There are a number of ways to try to mitigate the efficiency-reducing effects of this possibility, although all are imperfect. One approach involves assigning to the applicable government treasury a pre-determined share of the economic gains associated with a trade. However, such a share does not eliminate the possibility that the public sector agency's funding may be reduced in the following year. Nor does it eliminate the possibility that, in the future, the public sector agency may have to increase the revenue share it assigns to the applicable government treasury.

Another approach involves allowing government spectrum users to conduct trades on a barter basis. Such trades conceal the financial gains and, in so doing, reduce the possibility that the public sector agency's funding will be reduced. However, trading via a barter system creates its own set of problems. For example, suppose parties A and B wish to engage in a spectrum barter trade. A must be willing to give up the spectrum B desires and, moreover, B must be

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spectrum management.

23/ Voluntary trading has another important desirable feature. As noted earlier, public sector spectrum users are often very sensitive about releasing to the public information about their spectrum use requirements. Under a system that permits public sector spectrum users to trade their spectrum, such users can privately evaluate the different trade-offs from executing a trade. This is in stark contrast to the current administrative procedure wherein public sector spectrum users are repeatedly asked to justify, in a public forum, their allocation and use of radio spectrum.

24/ The willingness of a commercial user of spectrum to its excess spectrum is reduced if a buyer can use the spectrum to provide a service currently provided by the sellers. A commercial user of spectrum willingness to complete a trade can be enhanced if it were able to sell its excess spectrum subject to the restriction that the buyer not use the spectrum to provide a service currently provided by the seller.

willing to give up the spectrum A desires.25/ If each party has exactly what the other wants, it only takes one trade to improve each participant's welfare.26/ However, even if each party finds partners with opposite wants, this does not mean that such trades maximize allocative efficiency. Moreover, as the number of both tradable objects and parties interested in trading increases, the likelihood that one party will find another party with exactly the opposite wants declines. In such an environment, to consummate a spectrum trade, parties may have to become involved in a series of intermediate trades. These intermediate trades may involve significant transactions costs and information sharing between parties and, more importantly, will require the willingness of some traders to temporarily hold an undesired spectrum assignment.27/

The transactions and other costs incurred by individual parties could be reduced if a central "broker" was used to mediate trades. However, this refinement too suffers from high transactions costs as the central broker must send many messages to the respective parties informing them of the current willingness of the buyers and sellers to consummate a trade. Because buyers and sellers may believe that a better trade is just round the corner, the broker may have to deliver such messages repeatedly.

A seller may be hesitant to conduct a spectrum trade because of "performance risk." For example, government agencies often employ spectrum on an intermittent basis to, for example, coordinate relief efforts in the event of a natural or human disaster. It is often suggested that, because of the stochastic nature of such events, they should permanently occupy, on an exclusive basis, such spectrum. In permitting such an assignment, the existing spectrum management system treats such government spectrum users as if they are infinitely "risk averse."28/ The cost of such treatment is equal to the benefits society foregoes by not having the highest valued user employ

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25/ This hypothetical environment sometimes appears in actual situations. For instance, in attempting to improve the competitiveness of their teams, general managers often must conduct a trade on a barter basis (i.e., athlete for athlete). In general terms, in order for a trade to occur, each party must find a trading partner with exactly the opposite wants.

26/ For a more detailed explanation of a barter trading mechanism, see Ledyard, Porter, and Rangel (1994).

27/ In the sports world, a general manager may have to temporarily acquire the rights to a new player and, thereafter, package that player with one of the team's own players in order to complete a trade with a different team.

28/ A "risk neutral" entity selects bets on the basis of their expected value only. An entity is "risk averse" if it must be paid some amount in order to select a risky bet over a certain one when both yield the same payoff on an expected (utility) value basis. For example, suppose an entity was offered the choice between a sure $200 and a lottery ticket that yielded $400 with 50 percent probability, zero otherwise. This entity would be considered "risk averse" if it required a payment in order to select the lottery ticket.

such spectrum during periods of non-use by government users.29/ While it is possible that these foregone benefits do not exceed the value government users place on not having to assume any risk, it is not entirely clear that this is so. Currently, there is no process that generates information regarding the size of the risk premium government users demand and society's willingness to pay that premium. If latter value is greater than the former value, it would be possible to shift risk from government users to other users and, in so doing, make both parties better off.

Consider the following example. To assist it in extinguishing forest fires, the U.S. Forestry Service has been assigned radio spectrum that covers the Rocky Mountains. Because most, if not all, forest fires in this region occur during the dry season (i.e., June - October), the Forestry Service may be willing to surrender its spectrum use rights during the wet season (November - May). However, its willingness to do so is limited by the expected harm it would experience if a forest fire occurred during the wet season. The Forestry Service may be able to eliminate its risk if it traded its use rights subject to the condition that the buyer surrender its acquired spectrum to the Forestry Service in the event of a forest fire during the wet season.30/

The contract's surrender provision creates a "call" option. In general, a "call" option is simply a provision that grants a buyer the right to use the asset subject to some condition. For instance, the U.S. Treasury and corporations often issue callable long-term bonds. Under the "call" provision, the issuer has the ability to retire the bonds at a predetermined (i.e., redemption) price. The call option allows the issuer to retire the bonds early, thereby permitting it to refinance at lower rates should interest rates decline. However, because the call option shifts risk from the seller to the buyer, the buyer of the bond will demand a risk premium in the form of a higher interest rate or, as in the instance of commercial property or the placement of debt, a pre-payment.

In the Forestry Service example, a call option transfers the risk associated with a forest fire in the wet season from the Forestry Service to the buyer. The benefits of the call provision to the Forestry Service will be offset by the lower bid prices placed on the spectrum for sale or

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29/ While the current spectrum management process treats government users as if they are infinitely risk averse, it is not clear that they are in practice. If they are not, it may be possible to induce government spectrum users to assume risk in exchange for a payment that compensates them for assuming risk.

30/ In order for the risk to be completely eliminated the Forestry Service must have the technical means to ensure that the current users do not have the ability to employ the called spectrum.

lease. The discount in the submitted bid prices measures the premium that bidders demand as a result of taking on the risk that a forest fire may occur in the wet season.31/ In practice, public sector users should have the flexibility to tailor the call contract in a manner consistent with their risk profile. For example, the Forestry Service may elect to assume some risk (i.e., shorten the period over which the spectrum is callable) believing that the risk premium it would receive -- in the form of higher bids -- would more than compensate it for the additional risk it would assume.

The creation of a call option would unambiguously increase the efficiency with which spectrum is assigned. This increased efficiency would enable society to avoid foregoing valuable services as a result of treating government users as being infinitely risk averse. Assuming that the government users have the technical means to ensure that the current users do not have the ability to employ the spectrum, government users can not be made worse off through the adoption of such a policy. Under these conditions, government users should be willing to trade their spectrum for any positive price.

A. Preemption Rights and Beacon Signals

The price at which the seller is willing to release its spectrum to another user will depend, in part, on the seller's confidence that it will have access to the spectrum when it exercises its preemption right. The lower the seller's confidence, the less meaningful is the notion of releasing spectrum on a preemptable basis and, thus, the smaller the distinction between releasing spectrum on a preemptable versus non-preemptable basis. The less meaningful this distinction, the lower the likelihood of a spectrum trade. However, technology is now available that can give the public sector spectrum user high confidence that it will be able to regain nearly instantaneous use of spectrum. This can be done with a combination of software radio technology and special types of radio beacons operated by the public sector spectrum user.

Software radio technology is becoming increasingly common in mobile and other radios. Under this technology, software and a microprocessor control a set of radio functions, including transmitter frequency and power. Such technology makes it possible to program complex

31/ The price bidders are willing to pay for spectrum offered by the Forestry Service will reflect the cost they expect to incur if the spectrum were ever called. Bidders may be able to lower their risk by writing contingent contracts with owners of substitutable spectrum.

decision rules into the radio.32/ The use of beacons to control the functionality of nearby transmitters was an important issue in the Federal Communications Commission's "Big LEO"/Iridium rulemaking proceeding.33/ Although not adopted in that context, a variant of that idea appears promising in the context of sharing public sector spectrum. In this context, a public sector spectrum user that chooses to allow others to use its spectrum during periods of low utilization operates a beacon transmitter in or near the band in question.34/ This beacon transmits a coded signal indicating whether and what spectrum is available at that moment. The coded signal includes an electronic signature that validates the source of the beacon and information indicating that it is not being "spoofed" by an unauthorized party..35/ The spectrum user that has acquired the use of the spectrum must have transmitter software that checks repeatedly for the beacon signal. If the user's transmitter fails to receive the beacon signal for *x* seconds it must immediately cease use of the public sector spectrum. The public sector spectrum user, thus, is guaranteed the ability to reclaim the use of its released spectrum within *x* seconds. In addition to controlling if the spectrum is called back, the public sector spectrum user determines when the spectrum is called.

Callable or preemptable spectrum is similar to interruptible gas and interruptible electricity, the latter two of which have become a common basis upon which buyers acquire utility service. Such interruptible utility service is priced lower than non-interruptible utility service and is of interest users that do not place a premium on guaranteed continuous service. While interruptible utility service does not satisfy the needs of hospitals or other users that demand guaranteed continuous service, industrial processing facilities (e.g., electricity-intensive aluminum ore (i.e., "bauxite") processing facilities) often acquire a portion of their electricity needs on an interruptible basis. When a portion of their electricity supply is interrupted due to high electricity demand, the processing facilities adopt a slower processing scheme powered by

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32 For information about the regulatory history of software radios, see the record of Docket 00-47. http://www.fcc.gov/oet/dockets/et00-47/. Background technical information can be found at http://www.sdrforum.org/sdr_primer.html .

33 In this proceeding concerns were raised regarding signal interference between radio telescopes from NGSO satellites.

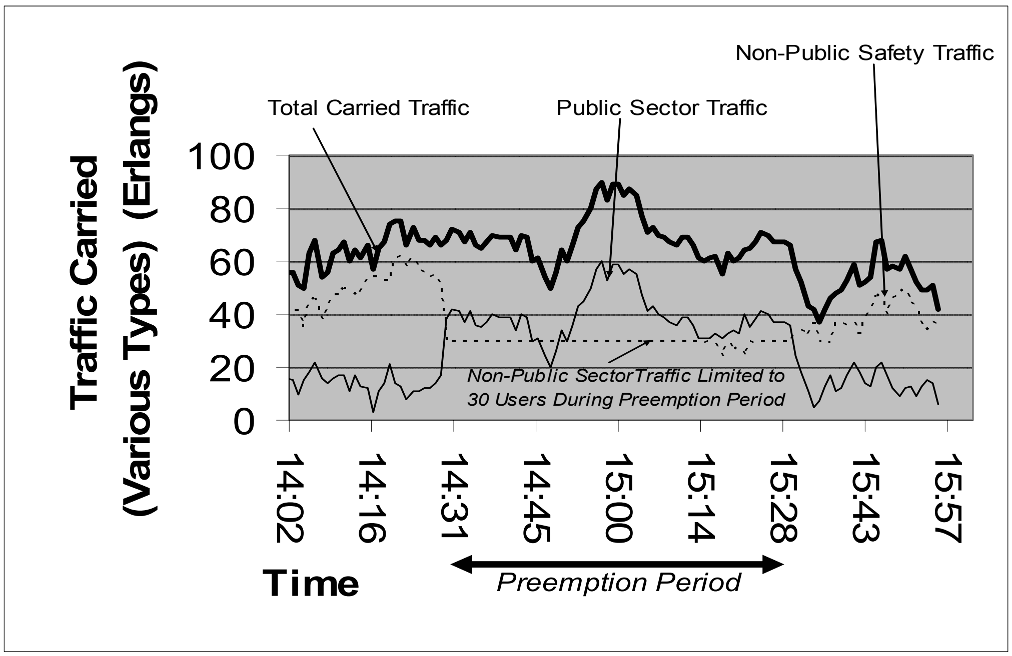
34 Market forces should determine the amount of compensation such a user receives from releasing its spectrum to another user.

35 Background information on electronic signatures can be found at http://www.abanet.org/scitech/ec/isc/dsg-

non-interruptible electricity. To consumers of interruptible electricity, the reduction in their electricity payments more than compensates them for the risk they assume in having their electricity supply interrupted.

It is easy to imagine a similar scheme being applied to the use of radio spectrum. For example, a commercial spectrum user might combine non-interruptible spectrum with interruptible spectrum obtained under agreement with a public sector user. The non-interruptible (i.e., non-callable) spectrum would be available at all times and could be employed by the user to maintain a certain level of operation if and when the public sector user exercises its preemption right. An illustration of this, based on computer simulation, is shown below.

Figure 1: Illustration of Interruptible Spectrum Use



The dotted line in the chart shows commercial traffic/users that have access to both public sector spectrum and 30 channels of dedicated commercial spectrum. The thin solid line represents the volume of public sector traffic. The use of the public sector spectrum by the commercial user is preempted at 14:31 by a sudden surge in public sector traffic. During this period, the commercial user is limited to his 30 channels of commercial spectrum. At 15:31 the

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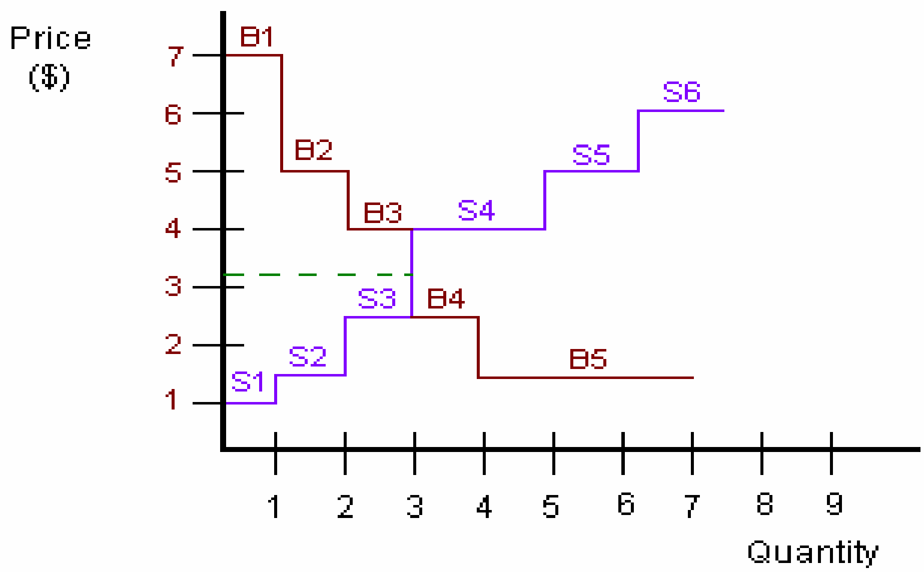
public sector use drops and the commercial user resumes its use of both public sector spectrum and 30 channels of dedicated commercial spectrum. What types of service might be offered using this type of configuration? One possibility might be a cellular telephone type of service that provides a lower grade of service (e.g., lower voice quality, increased dialtone delay) during periods of high public sector spectrum use. Alternatively this type of spectrum might be of interest to a two-way paging ("Blackberry™") service in which service speed or maximum message size decreases during periods of preemption. Importantly, the degree to which buyers will be attracted to preemptable spectrum will depend upon the discount they obtain from acquiring spectrum on this basis compared with the value of the preemption risk they assume.

E. TRADING VIA AN ELECTRONIC CALL MARKET

Spectrum license trading can be facilitated through a variety of mechanisms. Each mechanism should be evaluated based upon its ability to minimize "search costs" (i.e., costs that buyers and sellers incur in finding each other) and, in general, its ability to generate the set of trades that maximizes the economic gain traders earn (i.e. traders' surplus). Any other set of trades imposes a cost on society either in the form of foregone gains from trade, or search and other costs prospective traders incur in attempting to reach the traders' surplus maximizing set of trades. An "electronic call market" is a mechanism that attempts to maximize traders' surplus while at the same time enhance liquidity.36/ Under such a mechanism, buyers and sellers submit bids to buy and offers to sell spectrum at a pre-specified time. In the current context, bids represent the maximum amount buyers are willing to pay for a specific band of spectrum, while offers represent the minimum amount sellers are willing to receive in exchange for their spectrum. Bids are then ranked in descending price order to form a market demand curve, while offers are arrayed in ascending price order to form a market supply curve. Figure 2 presents a set of hypothetical supply and demand curves for a homogeneous collection of spectrum.

36/ For a more detailed discussion of the application of this mechanism for the assignment of radio spectrum, see Bykowsky, M. and Olson, M. (1999) "A 'Smart Market' for the Trading of Radio Spectrum," submitted to the Radiocommunications Agency of the Department of Trade and Industry (United Kingdom) on behalf of MediaOne International.

Figure 2: Demand and Supply Curves



Each "step" in the respective curves represents a buyer/seller. The width of each step indicates the amount of spectrum the prospective buyer or seller wishes to trade. Given the hypothetical demand and supply curves, three units of spectrum are sold at a uniform price between $2.50 and $4.00.37/ The point at which the supply and demand curves intersect identifies a "market clearing price" in that at this price both buyers and sellers have no incentive to increase or decrease the number of trades.38/ Importantly, at this price traders' surplus, based upon the bids and offers submitted to the market, is maximized. By consolidating bids to buy and offers to sell over time and executing trades simultaneously, an electronic call market increases the number of counter-offers that exist in the market at that instant, thus promoting

37/ Figure 2 assumes that the rules of the exchange set the price equal to the midpoint of this range. Given this price, Area A represents the monetary value of the economic gains obtained by the buyers, while Area B represents the economic gains obtained by the sellers. The sum of these areas represents the maximum economic gain generated from a collection of trades between buyers and sellers in this market (i.e., traders' surplus).

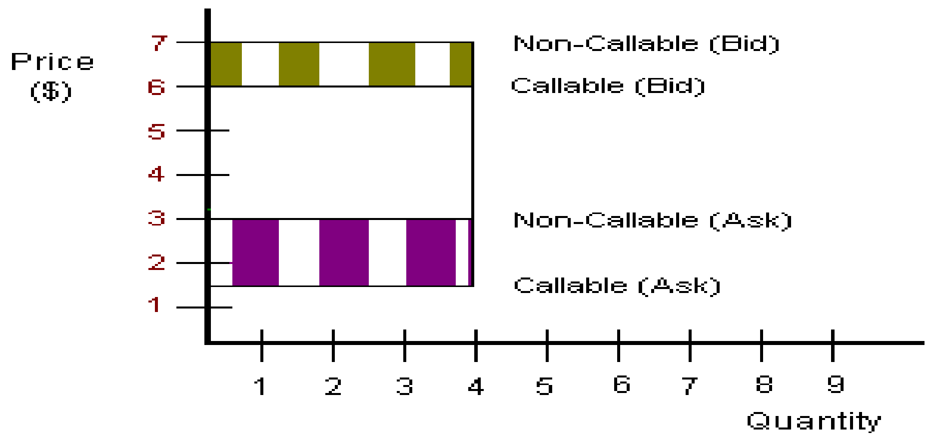
38/ Whether an exchange identifies the set of trades that maximizes traders' surplus depends importantly upon the market liquidity.

A. *Trading Callable Spectrum*

Importantly, an electronic call market can facilitate the trading of spectrum where the sold spectrum can include a call option. This can be shown through a simple example. Suppose a single buyer and a single seller wish to trade some spectrum. Under an electronic call market, each party would be requested to submit two market orders. For the buyer, one "bid" represents its willingness to pay if the spectrum was acquired on a non-callable basis, while the second bid represents its willingness to pay if the spectrum was acquired on a callable basis. For the seller, one "ask" represents the minimum amount it is willing to receive in exchange for its spectrum if its spectrum was sold on a non-callable basis. The second "ask" represents the minimum amount it is willing to receive in exchange for its spectrum if the spectrum was acquired on a callable basis. Figure 3 presents a set of offers and bids submitted to the market by these hypothetical participants.

rules of the exchange.

Figure 3: Callable and Non-Callable Bids and Asks



First note that because the bids are greater than the submitted asks, gains of trade exist whether the spectrum is traded on either a callable or non-callable basis. To maximize allocative efficiency, however, spectrum must trade on the basis that maximizes the total surplus enjoyed by the buyer and seller. Consider first the buyer's bids. The difference in the two bids reflects the premium the buyer is willing to pay if it were to acquire the spectrum on a non-callable versus callable basis. Similarly, the difference in the two offers reflects the premium the seller demands if it were to sell its spectrum on a non-callable versus callable basis. If the premium that the seller demands for releasing its spectrum on a non-callable basis is greater than the premium the buyer is willing to pay for acquiring spectrum on that basis, allocative efficiency considerations require that the spectrum be traded on a callable basis. In this example, given the risk preferences of the buyer and seller, spectrum should be sold on a callable basis.

F. CONCLUSIONS

The Public sector spectrum management process currently relies on administrative procedures to satisfy the long-term spectrum needs of public sector spectrum users. The metric by which economics measures the degree to which these procedures successfully satisfy such needs is based on the notion of "allocative efficiency." As an intellectual construction, the notion of allocative efficiency has few equals in the field of economics and, indirectly, public policy. The concept refers to the degree to which a given resource allocation maximizes the value society places on those resources, given the constraint that resource scarcity prevents all of us from being made better off. According to this concept, if resources are misallocated, then society's welfare can be enhanced by a simple re-distribution of the resources from those parties that currently own the resources to those parties that value them more. Moreover, if the correct trading mechanism is used, the redistribution can be accomplished in such a way that all parties are made better off -- thus making it politically acceptable.

The paper has shown that, under the current public sector spectrum management procedures, public sector users have an incentive to misrepresent the true value they place on spectrum. Consequently, it is extremely likely that an administrative procedure that attempts to allocate spectrum based upon assertions of "need" will misallocate spectrum among users. Moreover, this paper has shown that even if spectrum were to be efficiently allocated among users, there is no guarantee that the spectrum will be efficiently employed. Firms allocate resources in response to the relative prices (or opportunity costs). Rules that restrict who could acquire spectrum and how it can be used may distort such prices and, in so doing, lead to the economically inefficient use of spectrum.

This paper has shown that granting public sector users the ability to trade their spectrum allocations will improve the allocation of spectrum among users and, moreover, will promote its efficient use. There are numerous ways of encouraging trades between spectrum users. An "electronic exchange" appears to be the best mechanism. An important issue is whether traders should be permitted to use money as the medium of exchange. Permitting such use raises the concern that an approximation of the gains from trade (i.e., revenue) earned by sellers of public sector spectrum may be used by Congress to justify a reduction in the agency's budget. One solution is to commit Congress to a fixed percent of the gain from trade, or require that the spectrum users trade on a barter basis. It has been shown that the latter solution has its own problems. Another important impediment to a trade is performance risk. One solution to this problem involves granting public sector spectrum users the opportunity o release spectrum on a callable or preemptable basis. An electronic call market can be designed to provide public sector spectrum users that opportunity.