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Is re-farming the answer to the spectrum shortage conundrum?

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ABSTRACT

Radio spectrum has become one of the engines of economic growth. However, rapid technological change, ever increasing demands for new wireless services and the nature of spectrum as a scarce resource necessitate an urgent re-examination of issues such as congestion and interference.

This paper argues that the traditional administrative spectrum management approach is unlikely to overcome these issues, thereby resulting in growing technical and economic inefficiencies. As countries review their spectrum policies - a process that is generically referred to as 'radio spectrum policy reform' - to counter these inefficiencies, modifications to the radio frequency allocations and assignments are beginning to be implemented by way of 'radio spectrum re-farming'. This phenomenon forms the subject matter of this paper.

Keywords:

1. Introduction

Radio spectrum is a key economic resource that it is at the heart of the modern economy. It is central to dynamic new industries such as mobile telecommunications and creative industries like broadcasting, but as these and other industries have grown the demand that they have generated has placed unprecedented pressures on the radio spectrum that is available. Governments have also become aware of the value of radio spectrum, not least due to the third-generation mobile telecommunication auctions in Germany and the UK. Radio spectrum is no longer a resource to be freely given away for others to profit from, but one that can be sold to raise funds for the government.

Together these developments, which have led to growing technical and economic inefficiencies, have necessitated a review on the part of governments as to how they allocate radio spectrum. These reviews, which are often referred to generically as 'radio spectrum policy reform' usually require modifications to radio frequency allocation and assignment through a process called 'radio spectrum re-farming'. This paper focuses on radio spectrum re-farming, and asks whether it is able to resolve the emerging technical and economic inefficiencies.

With this in mind, the remainder of the paper is structured as follows. The following main section introduces key radio spectrum management issues, and is followed by a discussion of pricing methods. The fourth main section of the paper outlines the challenges that have cast doubt on the efficacy of the traditional approach to spectrum management, thereby laying the foundation for the subsequent introduction of re-farming in the following section. The sixth main section recounts the available methods for re-farming radio spectrum, with section seven focusing solely on administrative incentive pricing. In the final section of the paper, conclusions are drawn.

2. The management of radio spectrum

Radio spectrum is the distribution of radio frequencies with each frequency representing a portion of the radio spectrum. Radio spectrum is a finite but non-exhaustible resource (Cave, 2002a:5). It is considered finite because the range of the radio frequencies that is suitable for wireless communications is limited to the range from 9 kHz to 3000 GHz (Cave, Foster and Jones, 2006:2). It is also non-exhaustible because it is not consumed by use; in other words, radio spectrum is infinitely renewable (Hatfield, 2005b:1). When using the spectrum for a specific application, the same amount of spectrum can be used subsequently for another application. However, what distinguishes spectrum from most other resources is the fact that one user of spectrum might have an effect on other users – a phenomenon known as interference (Taschdjian, 2006:1). The interference problem necessitates a special kind of management to ensure coordination among the various users.

The governance of spectrum use on a global basis is the responsibility of the International Telecommunication Union's Radiocommunication Bureau (ITU-R). ITU-R's role is to achieve efficient and economic use of the radio spectrum by all radio communication services, including those using satellite orbits, as well as the carrying out of studies and the adoption of recommendations on radio communication matters (Cave, Foster and Jones, 2006:6). Technical matters are discussed by ITU-R study groups and confirmed at World Radiocommunication Conferences (WRCs). The use of spectrum is governed by the Radio Regulations which are updated according to the decisions made at each successive WRC (Raisanen and Lehto, 2003:5).

One of the main responsibilities of ITU-R is to distribute the radio frequencies among the different radio services. This process is called the allocation of the frequency bands (Stine and Portigal, 2004:40). In order to allocate the frequencies, the spectrum is divided into different bands (e.g. Ultra High Frequency (UHF) in the 300-3000 MHz band) and each band is better suited to certain services compared to others. Relevant services include broadcasting, mobile/cellular, satellite, public safety and two-way radio (Stine and Portigal, 2004:26). However, the frequency assignment process is the authorization for the use of a radio frequency to a user and that is the responsibility of each national regulator (Stine and Portigal, 2004:40).

Radio Spectrum as a Scarce Resource

Whether spectrum is truly scarce has recently been questioned and there has also been considerable debate concerning whether any perceived scarcity is real or artificial. The debate started with the emergence of equipment suitable for unlicensed spectrum as in the case of Wi-Fi. Equipment such as cognitive radios is smart enough to distinguish between signals and hence does not suffer interference, in which event spectrum reveals itself to be not scarce but abundant (The Economist, 2004). Moreover, technologies such as Ultra Wide Band (UWB) increase the availability of the spectrum through the more efficient use of spectrum that is already allocated (Pujol et al., 2007:48). Ryan (2005, 29) argues that the developing of unlicensed equipment, which is capable of providing the same services that licensed equipment can provide, has shifted the spectrum scarcity paradigm.

In addition, the scarcity of spectrum might increase as a result of the choice of the method of management. It can be argued that the traditional regulatory approach resulted in an artificial spectrum scarcity that was not due to any technical or market capacity constraints. As noted by Wellenius and Neto (2005:3), "Spectrum scarcity partly results from the spectrum management regime itself. Spectrum shortages coexist with overall underutilization and inefficient use". Moreover, in some cases a new service which could offer similar performance to an existing service, but at a lower cost, might emerge.

It can be argued from the above that spectrum is not necessarily scarce and that any shortage can be ascribed to spectrum access problems where such problems result from traditional methods of management that restrict the user's access to the spectrum (Minervini, 2007:107). However, two important issues should be taken into consideration when discussing spectrum scarcity: Firstly, spectrum is not a homogeneous resource as every spectrum band is better suited to certain services than to others due to the spectrum's propagation characteristics. Some applications may involve a very short distance (e.g. a wireless mouse) while others may need a very long distance (e.g. radar). Hence, the question is not only whether or not there is enough spectrum for a specific application, but also whether the available spectrum is suitable for that application.

Secondly, it is assumed that new technologies such as smart radio will be able to co-ordinate fully with one another and thereby avoid any interference. The previous discussion ignores the fact that such equipment is complex and expensive. Moreover, it would require a long period of time to test such equipment before it can be used in public services such as fixed-wire and cellular. In addition, the initial findings of a study by the European Commission examining the usage of interference management techniques instead of traditional methods such as limiting the technical parameters of transmitters, suggest that this alternative approach has its own limitations and can be applied only in specific cases (Sims, 2007).

Radio Spectrum Utilization

Spectrum efficiency can be defined as the least amount of spectrum that can be used to transmit a given amount of information (Federal Communications Commission, 2002a: 5). The amount of the spectrum has three constituents (International Telecommunication Union (ITU), 1997: 2): frequency bandwidth, geometric area and time. Fast information transfer rates need higher frequency bandwidth. The geometric area includes the transmitter and the receiver. The time factor can be ignored if the operation is continuous.

However, the previous definition ignores many factors and focuses only on sending the maximum amount of data over the available bandwidth. Burns (2002: 1) accordingly approaches the matter from a different perspective via technical efficiency, economic efficiency and functional efficiency. Technical efficiency means sending the maximum volume of data or voice traffic with a given amount of spectrum resource. The main objective of such approach is to distribute spectrum users in a way that does not lead to excessive interference. In addition, it aims at assigning the spectrum in a harmonized way on an international basis and at imposing specific allocations to ensure ubiquity of services.

Economic efficiency occurs when all inputs are deployed in a way that generates the maximum revenue, profit or added value from a finite amount of spectrum resource. To achieve such efficiency, the regulator should make sure that the spectrum price reflects the marginal benefit. At such a price, supply will equal demand as only the user, who gains the most benefit from a spectrum license will be willing to pay that price (Falch and Tadayoni, 2004: 205).

Functional efficiency is measured by the extent to which the use of spectrum meets a user's specific needs in such a way that a particular task is carried out more efficiently or effectively than would otherwise be the case (Burns, 2002). In other words, it measures how the spectrum is suited to its purpose. An example would be the public safety service which private networks can provide more efficiently than the public GSM network.

Radio spectrum management

According to Pogorel (2007b) there are four main dimensions to any spectrum management regime, the first of which is allocation. The regulator can either harmonize services or permit service neutrality. Harmonization means allocating a frequency band to a service or category of services such as Wi-Fi in the 2.4 GHz band (Pogorel, 2007a). Harmonization is useful in reducing interference, reducing cross-border coordination requirements and reducing the prices of equipment. However, there might be cases where there is inefficient utilization of part of a harmonized band (Pogorel, 2007b) although it is often argued that harmonization underpinned the success of the likes of GSM in Europe so its shortcomings should not be over-played.

The second dimension is that of technology, which determines whether the service used in a specific band is restricted to a specific technology (standardization). Allowing any technology to provide a service is called technological neutrality. The advantage of standardization is that it allows large-scale production which lowers the cost of equipment. However, this might lead to the service being stuck with inferior technology

(Pogorel, 2007a: 7). This dimension is quite critical in cases where there is a choice between competitive technologies such as W-CDMA and cdma2000 for 3G.

The third dimension is that of usage rights, of which there are two options, namely exclusive rights or collective use. Exclusive rights are useful in reducing interference and in cases where spectrum trading is permitted. However, they could create barriers to entry and could underpin the hoarding of spectrum. In contrast, collective use promotes innovation and opens up the market for new players but also needs technical restrictions as there is a higher risk of interference (Pogorel, 2007a). The final dimension identified by Pogorel (2007b) is the assignment method, which includes administrative, market-based and license-exempt methods. Each of these three methods are elaborated below.

Regulators could in principle end up with a wide variety of different management regimes depending upon the manner in which the above are combined. However, in practice, there are three main regimes that have been widely adopted by regulators: command and control, market-based and commons (Pogorel, 2007b: 1). A command and control regime is usually based on harmonization of spectrum, standardized technology, exclusive rights and administrative assignment. A market-based regime is usually based on non-harmonization, technological neutrality, exclusive rights and market-based assignment. The commons approach is usually based on non-harmonization, technology neutrality, collective use and license-exempt assignment.

Under the administrative assignment method, the regulator decides how the spectrum will be used by designating appropriate uses, technologies and users (OECD, 2006: 14). The regulator also determines how long the licence will run and its associated obligations (WIK, 2006: 8). There are two types of awarding the license under this model: first-come, first-served and beauty contest. Using the first-come, first-served method, license applications are dealt with in the order of their receipt and the license is granted when the applicant fulfils the application criteria (ERC, 1998: 12). It is generally used when there is no shortage of spectrum. In contrast, a beauty contest requires the regulator to choose the winning applicant via a competitive process using comparative criteria previously decided (Hatfield, 2005a). This method is widely used to achieve non-market public interest benefits and to address policy objectives that the market fails to ensure (FCC, 2002a: 36).

Administrative assignment is considered to be the most effective method when international harmonization of spectrum use is required (OECD, 2006: 14). However, it usually results in old and less efficient technologies being used in the assigned spectrum (OECD, 2006: 14). Moreover, there is no guarantee that the license would be awarded to the entity that values it most highly (Hatfield, 2005a: 13). In addition, the criteria used in the beauty contest might not satisfy the requirements of transparency and non-discrimination (WIK, 2006: 11) and it could also be an expensive and time-consuming process (ERC, 1998: 12).

The market-based method was first suggested in 1959 by Ronald Coase who argued that auctioning spectrum to the highest bidder was much the most effective method of assignment (The Economist, 2004). This method mainly involves spectrum auctions and spectrum trading in a secondary market (Baumol and Robyn, 2006) and is held to create incentives for spectrum users to apply their spectrum to the highest-valued uses as determined by the market (OECD, 2006: 14). In addition, the method may remove artificial scarcities arising from the administrative allocation of the spectrum (Wellenius and Neto, 2005: 5). A combination of auction and spectrum trading could reduce barriers to entry (Cave, 2002a: 20). Moreover, the secondary market could offer auction bidders a safety net in case their business proves to be unsuccessful and could also provide companies that lost out in an auction with the opportunity to acquire a license, possibly at a reduced price (WIK, 2006: 13).

It can be counter-argued that interference might increase between users and that harmonizing spectrum bands for contiguous geographical areas could be a difficult task, which could, in turn, reduce the benefits from international harmonization and standardization (OECD, 2006: 15). In addition, it might allow spectrum hoarding by incumbents seeking to restrict competition (Wellenius and Neto, 2005: 6) and there are concerns that auctions usually result in raising the value of a license and in delaying the deployment of services (Cave, 2002a: 20). Path dependency problems may emerge that could restrict future spectrum uses (Marks and Williamson, 2007: 74f). Moreover, the method could make it more difficult to impose social obligations on operators (Cave, 2002b: 126). Hence, the method is generally most suitable for frequency bands where scarcity is relatively high and transaction costs associated with market-based negotiation of access rights are relatively low (OECD, 2006: 15).

License-exempt is the assignment method used under the commons approach. In this model, the spectrum is unlicensed and owned by every one. License-exempt is often referred to as an open or free approach (Lehr, 2005: 3). In such approach, radio interference can be considered as a technological problem. Given the availability of smart radio and antennas, interference is resolved automatically by the users themselves with no intervention by the regulator (The Economist, 2004).

This should encourage innovation in the development of unlicensed equipment so long as it meets with technical constraints such as the permitted maximum transmitted power (Hatfield, 2005b: 8). In addition, this approach would reduce congestion in the licensed spectrum bands. Moreover, a common approach could enhance competition as competitors can easily enter the market at any time and this might help low-income users and those in rural areas (Panasik, 2004: 2). It has also been argued that license-exempt could be considered to be one of the market-based methods since the market would decide which applications are successful, not the regulator (Tonge and Vries, 2007: 89).

However, when a resource such as spectrum is shared between many users, individual users might increase their consumption by increasing their transmitter power in order to make more profit. This will cause additional interference to the other users and, as a result, they in turn will probably increase their own transmitted power creating yet more interference. This case is usually called the commons tragedy (Hatfield, 2005b: 9). Moreover, this could lead to an increase in the cost and the complexity of equipment (Hatfield, 2005a: 27).

The problem of interference differs from one service to another. Although interference is not acceptable for licensed users, as it would lead, for example, to excessive numbers of dropped calls, it might be acceptable for unlicensed users who do not pay any fees (Carter, Lahjouji and McNeil, 2003: 46). Moreover, in the license-exempt approach, the demand is managed by declines in the quality of service rather than by price increases (Tonge and Vries, 2007: 96).

The license-exempt approach is generally suitable for frequency bands where scarcity is relatively low and the transaction costs associated with market-based negotiation of access rights are relatively high (Federal Communications Commission, 2002a: 36). However, in response to the problem that few frequency bands are assigned to unlicensed services, a new assignment method has emerged known as the easement assignment method which has its roots in the development of new technologies such as software radio and ultra wide band (UWB). Under the easement method, the unlicensed users with smart technologies use the same spectrum assigned to licensed users (OECD, 2006: 16). The licensed user is treated as a primary user who can cause interference to the unlicensed user who is treated as a secondary user. However, unlicensed users cannot cause any interference to licensed users and cannot complain about the licensed users' interference. Such an approach could potentially reduce the high transaction costs incurred by new users when entering the market (Wellenius and Neto, 2005: 10).

3. Radio Spectrum Pricing Methods

The assignment of spectrum is often supplemented by imposing a charge for spectrum use. Charging facilitates the allocation of scarce resources and conveys information about the supply and demand for spectrum (Mueller, 1982). Moreover, charging is a major factor in utilizing the spectrum as too high a price might lead to under-utilization of the spectrum while too low a price might lead to hoarding and congestion (Cave, Doyle and Webb, 2007: 167). Ideally, charging should be considered as a tool for rationalizing the usage of the spectrum and not as a way to gain more income for a country (Youssef, Kalman and Benzoni, 1995: 94).

The difficulty in fixing prices arises from the fact that it is quite difficult to price goods that are not traded in a market. With this in mind, the following sub-sections describe the three main methods that are used to charge for spectrum, namely, administrative pricing, auctions and secondary markets.

Administrative pricing

Administrative pricing is usually associated with the command and control spectrum management approach. In all, there are seven main methods in use: differential, incentive, opportunity costs, periodic administrative cost recovery, shadow, spectrum re-farming and user profit pricing. Each of these sevens shall be addressed in turn.

Differential pricing measures the difference between the equipment costs of systems providing the same service but using different spectrum bands (Nozdrin, 2003: 80). In contrast, incentive pricing aims at providing some incentive for the user to utilize the spectrum efficiently. It is based on measuring the system performance in terms of the amount of spectrum used, number of links, transmitter power, coverage area, geographical location and other technical factors: the better the system performance, the lower the license fees. The disadvantage of this method is that the choice of values for the coefficients in the formula is not based on market needs (Ibid.: 79). In order to avoid a large discrepancy between the charge and market value, the incentive price formula should be linked to a market valuation (ITU, 2004: 25).

Opportunity cost is defined as the value of something in its best alternative use. In the case of spectrum, it means the alternative value that is foregone when a section of frequency spectrum is assigned to a particular user (Taschdjian, 2006: 5). It is intended to ensure that decisions by spectrum planners and users reflect the value of the spectrum not just to themselves but also to other users (DTI, 2007: 13).

Periodic administrative cost recovery pricing, which is also known as regulatory pricing, is based on recovering the annual costs of spectrum management by the regulator (Taschdjian, 2006: 5). The benefits of this method are that it guarantees recovery of regulatory costs and usually results in low prices. However, the method does not calculate the real economic value of the spectrum (ERC, 1999: 3). In addition, the method is unable to send appropriate signals to users in cases where parts of the spectrum are more attractive than others (Doyle, 2007b: 1). This method could, however, be used in the long run if the scarcity of spectrum gradually reduces (Youssef, Kalman and Benzoni.1995: 94).

The economic definition of a shadow price is "a competitive price for a resource such as would be established in an open market if there are many buyers in the market, none possessing any monopoly power to elevate the price of the resource by withholding the resource from the market" (Nozdrin, 2003:81). The method depends on how much operators are ready to pay for the right to use spectrum taking into account potential profit. As with the differential pricing method, the calculation might be both difficult and unrealistic since the potential profit of the industry could depend on many factors other than spectrum. In addition, the method does not take into account the alternative usage of the spectrum (Mueller, 1982).

Spectrum re-farming pricing is only used in cases of re-allocating a spectrum band and cannot be used as a general spectrum pricing method (Nozdrin, 2003: 79).

In the user profit pricing method, the license fee is based on the profit derived from the use of the spectrum. This method allows the regulator to derive a significant income from certain services. However, such a method cannot ensure the efficient use of the spectrum (Nurmatov, 2001:2).

Auctions

According to Taschdjian (2006: 6), "An auction is a market institution that uses bids from potential investors to determine the allocation of spectrum and its price". Auctions are usually used in association with spectrum trading for the initial placement of new or recovered spectrum in the market under a spectrum rights regime (Wellenius and Neto, 2007: 10). The main advantage of an auction is that it gives an accurate method for valuing spectrum (ITU, 2004: 15). In addition, the auction process is relatively objective and transparent (Hatfield, 2005a: 21). Cave (2002a: 20) recommends that auctions should be the default means of assigning licenses to exclusive frequency bands.

However, there are many limitations to the auction method. Firstly, revenues from auctions are not certain. In addition, imposing a minimum bid amount might give misleading signals to bidders. If the minimum is set too high, there is a risk that too few bidders will apply (ITU, 2004: 15). Auctions are generally used for large blocks of spectrum rather than for small amounts since in the latter case prices might end up too high (Indepen, 2006a: 38). It could also be argued that auctions allow big companies with large financial resources to acquire a large share of the spectrum from which they could derive monopoly power (Baumol and Robyn, 2006: 36). Moreover, their use might encourage a regulator to maximize revenue to the national treasury rather than to seek the most efficient use for the spectrum (Hatfield, 2005a: 23).

Secondary markets

According to Cave, Doyle and Webb (2007: 39), "Trading can lead to a more economically efficient use of frequencies. This because a trade will take place only if the spectrum is worth more to the new user than it was to the old user, reflecting the greater economic benefit the new user expects to derive from its use".

There are, however, counter-arguments. The ITU recommendations on spectrum pricing summarize four cases where secondary markets would not be feasible, namely where:

- Some of the government's critical goals, societal needs or research requirements may not be achievable.
- Rich users hoard most of the spectrum, with the consequence that other users would be denied access to the spectrum.
- Certain band should be allocated to certain uses on a large scale to facilitate equipment production.
- In order to have one standard for a specific service, spectrum for this service should be allocated in a harmonized way (ITU, 2004:16).

4. Radio Spectrum Management Challenges

In recent years many challenges have emerged to cast doubt upon the efficacy of the traditional approach to spectrum management. These include the following:

- An increased demand for spectrum due to evolution in communications technologies. For example, 3G and 4G cellular require increased spectrum bandwidth compared to 2G.
- Globalization which requires that the assignment of spectrum is internationally harmonized to the greatest extent feasible.
- The increased complexity of interference management.
- Allocating the spectrum by service becomes increasingly difficult due to convergence: most modern technologies provide audio, data and video. .
- The distinction between fixed and mobile service has become muddied with fixed-wire operators attempting to add mobile or nomadic features to their service and mobile operators attempting to use low cost land calls and broadband as part of their service (Goggin, 2006: 240).

However, two issues stand out. Firstly, new emerging technologies like UWB and cognitive radio are threatening the legacy model. Unlike other wireless systems which use spectrum in discrete narrow frequency bands, UWB is capable of sending very high data rates over a wide frequency bandwidth for short distances (Pujol *et al.*, 2007: 14). In addition, UWB equipment transmits at power levels below the noise floor so it theoretically has no impact on other receivers although not everyone is convinced. Moreover, cognitive radio is a smart device which is able to interpret its environment and operate in vacant frequency bands (Evci and Fino, 2005). Although cognitive radio learns from experience, its behaviour, unlike that of other forms of thinking radios, might become unpredictable (Pujol *et al.*, 2007: 22). Such technologies would force the spectrum manager to change the assignment method as the concept of exclusivity is totally different in this case. However, it should be noted that exclusivity offers not only protection from interference to current users, but also protection from potential competition (Goggin, 2006: 241).

Secondly, congestion is due to inefficiency in utilizing spectrum (Cave, Doyle and Webb, 2007: 209). Spectrum utilization inefficiency could exist in two situations (FCC, 2002a: 16): a situation in which all spectrum in an area is already assigned but not fully used and/or a situation in which all spectrum is already assigned and fully used but not in an efficient way. The first situation could exist in cases where governmental agencies hold spectrum in excess of their needs. The second situation could exist when a user is using an old technology and not best utilizing the spectrum.

5. Radio Spectrum Re-farming

The policy reform process usually requires modifications to the existing radio frequency allocations and assignments in order to achieve the new policy objectives. The process of spectrum modification is usually called 'Radio spectrum re-farming'. The ERC (1998: 25) define radio spectrum re-farming as follows:

> Spectrum re-farming is a spectrum management function and is the physical process by which a spectrum management authority recovers spectrum from its existing users for the purpose of reassignment, either for new uses, or for the introduction of new spectrally efficient technology.

In other words, spectrum re-farming means revising and changing the way the spectrum is utilized. According to Indepen (2006a: 54), change could occur in one or more of the following: in the application or the use; in the technology used; in the technical characteristics of the license such as the frequency bandwidth or the maximum transmitted power; and, in the licensee. It is also worth noting that spectrum re-farming does not necessarily imply the removal of licensees from one spectrum band to another but rather the re-allocation of spectrum in order to achieve greater utilization efficiency.

Indepen (2006a: 55) highlights five reasons for re-farming the spectrum. The first reason is where the benefits from the new use of spectrum exceed those of the existing use, whilst the second is that the international harmonization of spectrum may necessitate the re-allocation of frequencies. A third rationale for re-farming is where existing applications could use spectrum in higher frequency bands but new applications could not, with a fourth being that there is congestion in a specific spectrum band. A final rationale is where sharing between an existing service and a new service is not technically feasible.

There are additional reasons for re-farming spectrum that can be summarised as follows:

- Where a number of inefficient assignments were made in the past and they no longer match the demands of licensees or the capabilities of modern systems (ITU, 2003:2).
- Where a new technology requires access to the spectrum in a specific band.
- Where existing licensees are using an old technology which could be replaced with a more spectrum-efficient technology.
- Where the public sector hoards spectrum beyond its known needs.
- Where a decision is made by the ITU to allocate a currently occupied frequency band to a different service on a regional or global basis (ERC, 1998:25).

At the end of the day, re-farming the spectrum should be considered only if there is a potentially higher value use for the frequencies. The benefits of the re-farming process are the sum of consumer and producer surpluses plus any dynamic benefits such as those that arise from competition, less costs associated with the re-farming process (Ovum, Indepen and Aegis, 2006:81).

6. Methods for Re-farming the Radio Spectrum

In some cases, when the re-farming process involves some forced adjustment of existing frequency assignments, the process becomes difficult and requires the consideration of all available options. These could include a combination of administrative, financial and technical measures (ITU, 2003: 1). Administrative measures could include license termination or a change in license conditions, financial measures could include incentive pricing or mitigation cost while technical measures could include the imposition of sharing in some bands or encouraging the use of frequency agile equipment (ECC, 2002: 14-16). The four main methods of re-farming spectrum suggested by Indepen (2006a: 56) are dealt with in the four following sub-sections.

License termination

The license termination method involves either terminating the license or refusing to renew the license (ITU, 2003: 5). No financial compensation is required after the notice period but lowering the license fees during this period is required in order to support the re-farming process (ERC, 1999: 19). This method should be used only in specific cases where evacuating the spectrum is urgently required.

Mitigation cost

It is common to use the expression 're-farming fund' when referring to the cost of mitigation. The re-farming fund is the compensation cost awarded to licensees if the administration reclaims the frequencies they are using (ERC, 1998: 26). Usually, the mitigation cost is employed when time cannot solve the congestion problem and when the re-farming process has to take place at short notice (ERC, 1999: 19). There is no need for the mitigation cost method in cases where spectrum trading is permitted since the spectrum will be transferred as a result of negotiation between the existing user and the new user (Cramton, Kwerel and Williams, 1998: 1).

The mitigation cost depends upon many factors such as type of service, type of equipment and the occupied bandwidth. Although the most widely available equipment should be used as a basis for calculating the mitigation cost, it could be also a factor in reducing the total cost because of the potential benefits of using modern equipment (ECC, 2002: 21). In addition, consideration should be paid to whether the license is long-term or short-term and whether the license is about to expire as the mitigation cost is likely to be highest when the license is far from its expiry date (Cramton, Kwerel and Williams, 1998: 3).

The first option for calculating the mitigation cost is to take a fraction from the spectrum leasing revenue and give it to the licensee. Although this option appears to be simple, the revenue from spectrum leasing might not be adequate to cover the mitigation cost especially in the case of the public sector – in particular where the military are concerned. However, this could be solved by using an auction when leasing the spectrum with the reserve price set equivalent to an amount sufficient to compensate the existing user. Such a method is used in the USA (National Telecommunications & Information Administration, 2002).

A second option is to calculate the opportunity cost of using the spectrum. However, this option could be very difficult to employ in the case of the public sector since the concept of opportunity cost is totally different where achieving a profit is not a priority.

SpectrumWise (2006: 60) identify three main methods for the calculation of opportunity cost as follows:

- Estimate the cost of using alternative means for the deliver of information.
- Use overseas comparisons if the same spectrum band was used differently.
- Estimate the license fee revenue that the regulator could obtain if the spectrum was turned over to a new use.

A third option is to calculate the residual value of the existing user's equipment (ITU, 2003:10). Although this method is straightforward, it is not without its difficulties since investments made in the telecommunication sector are treated as sunk costs, which means that the resale value of the equipments is unknown (ECC, 2002: 38). The various options for the provision of the re-farming fund are to be found in ERC (1999: 23).

Alternative radio spectrum

The role of the regulator in this method is to provide alternative, less congested spectrum and to pay the licensee an appropriate mitigation cost. The difference between the alternative spectrum method and the mitigation cost method is that in the latter case the regulator is not required to provide alternative spectrum as in general the licensee has hoarded spectrum that in excess of needs. Alternatively, the role of the regulator is to use incentive pricing and to provide alternative frequency bands where a technology can be used. One option is to provide unlicensed spectrum to deploy the same service which can be deployed in a licensed band.

Radio spectrum pricing

Pricing could also be used in the re-farming process by way of lowering prices for frequencies where there is no congestion and raising prices for frequencies where there is congestion (ERC, 1999: 18). The main aim is to induce the licensee voluntarily to hand back the license and this process is accordingly known as 'voluntary re-farming' (ECC, 2002: 14). This process often takes 3 to 5 years to be successful (ITU, 2003: 7).

The problem with this method is the difficulty in moving all the licensees in a frequency band at the same time (Indepen, 2006a: 56). However, it could be useful in cases where congestion is highly specific (ITU, 2003: 8). It should be noted that using incentives to change the behaviour of licensees would only be effective if they were in a position to deploy an alternative means of providing a service.

7. Administrative Incentive Pricing

The previous section has discussed a range of methods that could be used in radio spectrum re-farming. It is clear from the discussion that no single method stands out as being superior to the others, with each having their own particular set of advantages and disadvantages. Having said this, the optimum pricing method would be one that achieves a successful compromise between technical, economic and functional efficiency. Given the advantages and disadvantages noted above, such a method would combine the opportunity cost method with the incentive pricing method that had been adjusted to take into account social factors.

Incentive pricing based on opportunity cost is known as 'administrative incentive pricing' (AIP) and combines the administrative and market approaches together.

Licences are issued through an administrative process while at the same time the fees are based on the opportunity cost. The method provides an incentive to the licensee to return excess spectrum or to use spectrum more efficiently. AIP is intended to ensure that decisions by spectrum planners and users reflect the value the spectrum not just to themselves but also to other users (DTI, 2007: 13). Pricing spectrum at a value closer to its economic value provides a disincentive to hoard spectrum (Smith-NERA, 1996a: 12).

It should be noted that secondary markets play no role in the re-farming process, as secondary markets do not apply in many cases. It is possible that there would be windfall gains from making spectrum tradable which would not provide incentives for more efficient spectrum use (Ovum, Indepen and Aegis, 2006: 95). However, secondary markets could be introduced in a later stage where the regulator would apply the AIP fees to the tradable license right. As stated by Office of Communications (2005: 13), "Ofcom believes that AIP should continue despite the advent of spectrum trading, as AIP can continue to promote greater efficiency".

AIP can be considered as the next best alternative to auctions and secondary markets in approximating the opportunity cost. AIP has been adapted successfully in many countries like Australia, New Zealand, Canada and United Kingdom. A pricing method that is based on the AIP method and is adjusted for social factors would the best administrative pricing method to be used in the re-farming process.

Before applying the AIP method to any service, consideration should be given to the purpose, processes, and operating environment of the service. Smith-NERA (1996a: 12) assert that AIP is only likely to result in benefits if it induces users to change their spectrum use and they note that such changes are likely to be slow to occur because of the significant investment in existing technologies and services. Hence, in cases where it is necessary to evacuate a frequency band for a specific service such as 3G or WiMAX within a matter of months, AIP would not be suitable. In any event, it would be very difficult to move all of the users simultaneously. The primary purpose in applying AIP is not to achieve any specific short-term change in the use of the spectrum, but to ensure that spectrum licensees fully recognize the costs that their use imposes on society (Cave, Doyle and Webb, 2007: 201). It should be noted that in cases where there is no alternative use for the spectrum, the price should be set solely to recover spectrum management costs (SpectrumWise, 2006: 58).

AIP in practice

Smith-NERA is one of the earliest methods for setting AIP values. It was published in a study by the Radiocommunications Agency (later folded into Ofcom) in the UK in 1996 (Smith-NERA, 1996a) and it was applied to two case studies, namely mobile radio (public and private) and fixed links (Marks and Yuguchi, 2004: 78). The method is designed to calculate the willingness to pay for a marginal unit of spectrum (Doyle, 2007a: 7).

Smith-NERA (1996a: 12) lay down four conditions, which if one or more hold true, ensure that administrative pricing will not be of value. These four conditions are as follows:

- There is unlikely to be excess demand for the spectrum either now or in the foreseeable future.
- There are political or policy factors which impede the application of spectrum pricing.
- It is not practically feasible to collect license fees.

- There is no opportunity for licensees to change their behaviour other than by abandoning their service, and in such an event the spectrum would be left idle.

Smith-NERA (1996a: 24) applied the above to the various services that occupy the spectrum to discover where administrative pricing is applicable. Three services were found to be eligible, namely satellite, fixed-wire (links) and mobile. This paper is concerned with the latter two only. The scheme illustrated in Figure 1 (below) can also be used to determine where to apply the AIP method.

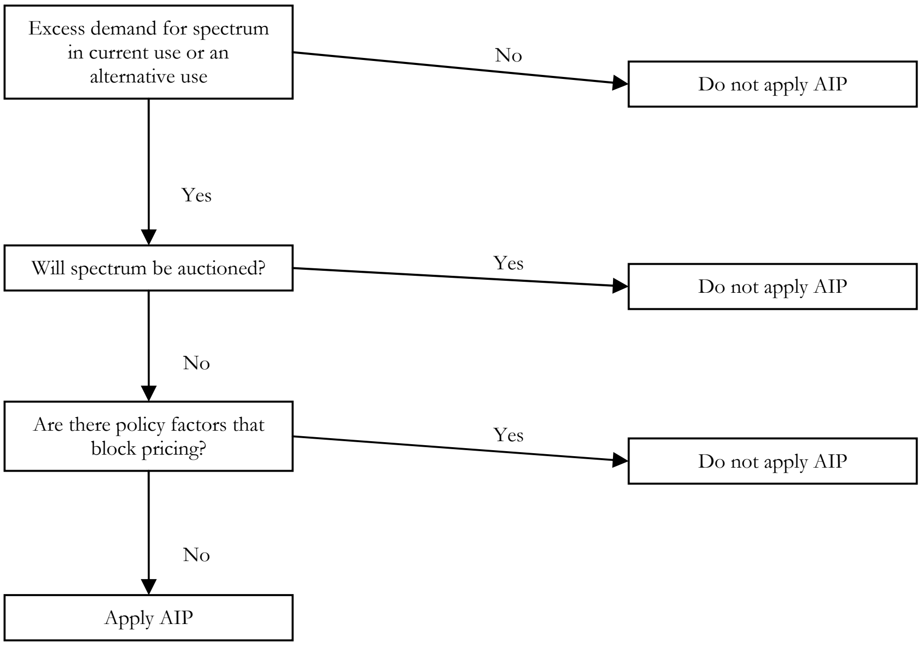

Figure 1: Conditions for Applying the AIP Method.

Source: Indepen (2006a: 36).

According to the authors of the Smith-NERA method, there are many limitations in the method (Smith-NERA, 1996a: 39) that are also reiterated in Doyle (2007a: 9) and Indepen, Aegis Systems and Warwick Business School (2004: 4). Nevertheless, AIP is still seen as the best administrative method in the absence of auctions and secondary trading As stated by Cave (2005: 35), "We do not see a feasible or better pricing mechanism for promoting efficiency in the use of spectrum that has not been auctioned". Cave (2006: 5) recommends continuing to work with the opportunity cost principle while extending it to the inter-relationships between different uses and frequency bands and also to the heterogeneity of users within frequency bands.

The Smith-NERA method was originally developed for the UK, though attempts have been made to generalise the method so that it can be used elsewhere. Cave, Doyle and Webb (2007: 188) suggest four steps to generalise the method:

- Identify current and other potential uses in each frequency band.
- Calculate the opportunity costs associated with each use by applying the least-cost alternative method.
- If there is a use with an opportunity cost higher than the current use, then set the AIP between the two values but towards the bottom end of the ranges of values.

- If there is no use with an opportunity cost higher than the current use of the band then set the AIP at the value of the current use.

Given the advantages associated with AIP, a natural question to ask is where has the method been applied and whether can common lessons can be learnt? The UK license fees scheme is based on the Smith-NERA method (WIK, 2006:87). The license fees depend mainly on three factors: location of radio operation, frequency band and exclusivity factor (Radiocommunications Agency, 2002). The scheme applies numerical factors to take account of various spectrum management factors such as competition, choice and diversity, quality of service and spectrum usage constraints (ITU, 2004:92).

Although the AIP method has succeeded in releasing 28 MHz in the spectrum below 3 GHz (Doyle, 2007b: 3) and in increasing the regulator's income by £160 million per year (Doyle, 2004a: 3), it is argued that AIP did not have any noticeable effect on incentives for efficient spectrum use because the price level was set too low (Ovum, Indepen and Aegis, 2006: 93). Eventually, the government agreed in 2006 that AIP would continue as a basis for spectrum pricing, that it should be applied more consistently and that it should more accurately reflect the market value of the spectrum (Cabinet Official Committee on UK Spectrum Strategy, 2006: 4).

In Australia the license fee is based on the amount of spectrum that a particular service denies to other users. License fees depend mainly on the demand for the different parts of the spectrum, the population in the geographic areas and the used bandwidths (ITU, 2004: 73). The pricing of the denied spectrum is based on the opportunity cost (Cave, Doyle and Webb, 2007: 199).

An incentive pricing scheme, which lowers the fees for users with low transmission power and a high frequency reuse factor, is used in Israel. The scheme succeeded in reallocating all point-to-point links on frequencies below 960 MHz to higher frequencies within two years (ITU, 2004: 81).

In the United States regulatory fees are intended to recover the cost of administration, which is unrelated to market value (WIK, 2006:127). Once the regulator determines the administration cost, the cost is divided by the number of licensees to obtain the license fee (ITU, 2004:95).

The Canadian pricing model is called Spectrum Efficiency Incentive pricing and it is based on two factors (Connolly, 2006:11): the consumption of the radio frequency spectrum and the relative scarcity of frequencies in a given area. The saturation index is used to measure the degree of the scarcity of the spectrum in a specific band and in a specific area. According to Industry Canada (1996:9), spectrum saturation is defined as the ratio of spectrum consumed to spectrum available in that geographic area. License fees for high-congested zones are nearly double those of medium congested zones and four times those of low congested zones (Industry Canada, 2003:17).

In a European Union study on the license fees relating to the use of spectrum, it was recommended that factors such as bandwidth and the frequency band should be taken into account and also that where there is scarcity in the spectrum, license fees should reflect the opportunity cost (Burns, Kirtay and Court, 2001:149).

From the above case studies it can be argued that the AIP method is widely used around the world and that it is mainly based on three factors: technical factors such as bandwidth, transmitted power and congestion in the frequency band; the opportunity cost of using the license; and social factors. The significance given to each of these three factors is, however, different between each of the countries mentioned.

8. Conclusion

It is clear from the above discussion that the allocation and pricing of radio spectrum is not straightforward as three sets of inter-related factors – technical, economic and social – need to be considered. Through technical advances and ever increasing demand for wireless services, the traditional model of managing radio spectrum has been challenged. Of particular significance have been the emergence of new technologies that question the traditional approach of allocating devices to specific spectrum frequencies on the one hand and the congestion that results from the inefficient use of spectrum on the other.

One answer to the challenges that have emerged is radio spectrum re-farming, which entails revising how spectrum is utilized. Whilst there is no single motive in the literature for implementing spectrum re-farming, it is clear that at the heart of spectrum re-farming is the notion that potentially higher value use will result when it is implemented. Although four alternative methods were discussed, it is argued that the optimum pricing method would be the one that offers the best compromise between technical, economic and functional efficiencies.

All things considered, administrative incentive pricing (AIP) offers the best compromise between these three areas as it based on a combination of administrative and market approaches. Moreover, in those countries where it has been implemented a social component has been incorporated as well. However, the four conditions suggested by Smith-NERA ensure that AIP is not appropriate in all cases. Having said this, where it has been used vividly demonstrates the interaction between several technical as well as economic factors. This interaction also demonstrates that AIP can be varied in its implementation, in other words, there is no 'one size fits all' approach but rather a method that is sufficiently flexible to take into account the specific national circumstances faced.

In conclusion: whilst it can be argued that spectrum re-farming does offer a way to address the problems that have emerged with the traditional spectrum allocation methods, it is not *the* method as suggested in the title. Rather spectrum re-farming can be regarded as being one of several methods that can be used to address the problems and challenges that are emerging as new technologies appear and demand for services continues to grow. It is, however, a particularly useful method due to its ability to combine administrative and market approaches and is thus likely to be one that is increasingly resorted to in the coming years.

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