THE ECONOMICS OF PRICING RADIO SPECTRUM

Chris Doyle
Senior Research Fellow, Centre for Management under Regulation, Warwick Business School, University of Warwick, Coventry CV4 7AL, United Kingdom
chris.doyle@wbs.ac.uk

ABSTRACT

Radio spectrum is a common access resource that can be used to support many different applications. This short paper outlines how economic principles can be applied to arrive at administered incentive prices for radio spectrum. Such prices accord with economic efficiency.

INTRODUCTION

Radio spectrum is a finite common access non-exhaustible resource that is used in many different applications, supporting both consumption and production activities. Over the last twenty years there has been a marked increase in the use of and demand for radio based services. Within households the use of radio has grown substantially, and the popularity of cellular telephony and wireless communications more generally has led to a substantial increase in the demand for radio spectrum. In this short paper I focus on the key economic factors affecting radio spectrum, that is demand and supply, and assess how these can be used to determine spectrum prices.

Unlike most other inputs used by firms in production, in most countries of the world it is currently not possible to trade radio spectrum frequency rights and obligations (notable exceptions are Australia, Guatemala, New Zealand and the United Kingdom (UK)). Following the passage of the European Union (EU) Regulatory Framework for Electronic Communications in 2002, member states of the EU may permit trading in spectrum (see article 9(3) of the Framework Directive, 2002/21/EC). The UK has introduced legislation permitting trade in radio spectrum (Communications Act 2003, Section 168), and the regulator OFCOM is currently consulting on proposals for spectrum trading.

Where markets are not permitted to operate they are said to be missing or incomplete and it is known in economics that this can give rise to inefficiency, particularly in circumstances where demand exceeds available supply. An obvious remedy to this inefficiency would be to allow trade in radio spectrum, and many practitioners view this as a desirable long-term policy solution.

However, shifting from the current command-and-control management of radio spectrum prevalent in most countries to a regime where spectrum trading occurs should be undertaken gradually. This is partly due to history having locked in many frequency bands to specific uses (e.g. through the international radio regulations managed by the ITU) and thereby limiting the extent to which trading can occur, partly because institutional arrangements to support spectrum trading require time to become established, and partly because there are many potential disruptions that be associated with a big-bang approach.

One gradual approach towards spectrum trading is via administered ‘incentive pricing’. The Radiocommunications Agency in the UK (now Ofcom) first introduced incentive pricing for radio spectrum in 1998. Incentive pricing is intended to promote economic efficiency by establishing administered prices that reflect (estimated) opportunity costs of radio spectrum.

In this short paper the economic rationale for ‘administered incentive pricing’ of radio spectrum is discussed. The structure of the paper is as follows. Section 2 discusses the allocation, assignment and characteristics of radio spectrum. In section 3 economic efficiency is discussed. Section 4 describes the application of the Smith-NERA least-cost-alternative method and its relationship to efficiency. Section 5 concludes.

ALLOCATION, ASSIGNMENT AND CHARACTERISTICS OF RADIO SPECTRUM

Radio spectrum S is a finite non-exhaustible common access resource extending between the frequencies 9 kHz and 3000 GHz. There are many public and private uses to which radio spectrum can be put, just as land can be used for many different purposes. International coordination has traditionally determined the uses to which radio spectrum is put and how much frequency is allocated to a use.[1] For example, the frequency range 87.5 MHz to 108 MHz is allocated to FM sound broadcasting providing national, regional and local VHF radio services.[2]

At the national level the use of radio spectrum S in most countries is currently managed closely by government agencies rather than by market forces. The management of spectrum by government is usually predicated on protecting property rights, promoting the benefits associated with coordinating use and national security.

In many countries the primary tool of spectrum management by government is a licensing system. Although some frequency bands, such as frequencies around 2.4 GHz, are licensed exempt and akin to a 'commons', the majority of frequencies require users to hold a licence from government to access radio spectrum.[3] Licensing effectively makes many frequencies bands in the radio spectrum a *de facto* private good.[4] The issuing of radio spectrum licences to users is known as the assignment of radio spectrum.

The allocation problem effectively involves the division of the radio spectrum S into a collection of frequency bands which are allocated to uses. Stating this formally, let $s \in S$ be a frequency within the radio spectrum, then for an integer $j \geq 1$ define $b_j=(s_{j-1},s_j) \subset S$, where $0<s_{j-1}<s_j$, as frequency band j.[5] If there are N possible uses for radio spectrum, the allocation problem may be solved by dividing S into N frequency bands b_j for j=1,...,N.[6]

There is little discretion in the short- to medium-term (which may be up to ten years) for individual national states to affect radio spectrum allocation. However, while fundamental changes to the way radio spectrum is allocated across uses is generally not feasible, changes to allocations at the margin are increasingly possible – giving scope for policy intervention. This could be achieved by setting administered spectrum prices a_j, where the price is set in relation to frequency band j.

RADIO SPECTRUM PRICING AND EFFICIENCY

The key policy question for radio spectrum pricing policy is:

- What factors ought to determine the selection of an administrative prices a_j?

In many countries the criteria for setting the prices for frequency bands has been driven primarily by cost recovery.[7] In some countries however, such as the UK, use has been made of Administered Incentive Pricing (AIP), where the primary criterion for setting prices is economic efficiency rather than administrative cost recovery 9though the two coincide where there is excess supply).

In a review [2] of spectrum management policy commissioned by the UK government it is stated that AIP ought to be chosen in a way that encourages productive efficiency:

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1 The United Nations organization the International Telecommunication Union oversees international coordination of radio spectrum via the World Radiocommunication Conference, see http://www.itu.int/ITU-R/conferences/wrc/index.asp.

2 By allocating this frequency range to VHF broadcasting, manufacturers of radio sets have designed equipment to operate around these frequencies. As a consequence, consumers possess equipment to receive VHF broadcasting within the frequency bands 87.5 MHz through to 108 MHz. While in principle it is possible to re-allocate these frequencies to another potentially higher-value use, there would in practice be a significant cost associated with reconfiguring or replacing the equipment used to receive sound broadcasting. In the future `smart radios' may lessen the need for such rigid allocations of radio frequencies, see http://www.sdrforum.org/ for information about software defined radios.

3 Licences provide both rights and obligations. Rights provide for access to specified frequencies at particular times, and obligations may include constraints on system apparatus (such as constraints on power, physical size, etc.).

4 An alternative way to manage radio spectrum would be as a commons, in much the same way oceans are managed. This approach has been discussed by [1].

5 The use of open intervals can be justified in terms of guard bands.

6 This is a simplification because in practice some uses share frequency bands.

7 Typically administrative charges a_j are set to recover the costs of spectrum management directly attributed to users, and may also include an element to reflect common (overhead) costs.

"The fundamental mechanism by which the spectrum management regime could contribute to economic growth is through ensuring that users face continuing incentives towards more productive use of this resource. The review considers that these incentives should be financial and based on the opportunity cost of spectrum use. In this way, spectrum would be costed as any other input into the production process. Price signals about the cost of using spectrum would be disseminated throughout the economy. This information should enable dispersed economic agents to make their own judgements about their use of spectrum and the alternatives open to them to meet their organisational goals."[8]

Opportunity cost is defined in [2] as: "the value of an asset or resource in the next best alternative that is foregone by virtue of its actual use."

A necessary condition for productive efficiency is the equalization of the marginal rate of technical substitution between inputs across sectors (and across firms within a sector). This suggests that for radio spectrum use to satisfy productive efficiency the marginal rate of technical substitution between radio spectrum and another substitutable input should be equal across firms in the same sector, and across firms using these inputs in different sectors.

The justification for ensuring that the use of radio spectrum satisfies productive efficiency can be found in [3] which states that a policy maker choosing taxes in a second-best setting should not tax the use of inputs. It is further stated that the use of inputs in a competitive economy should satisfy conditions necessary for productive efficiency if a second best outcome is to be achieved.

Setting the price for spectrum so that productive efficiency is promoted, both within sectors and across sectors, is therefore desirable. One method that can be applied to ensure productive efficiency is achieved is known as the Smith-NERA method, see [4].

THE SMITH-NERA LEAST COST ALTERNATIVE METHOD

The Smith-NERA method works by identifying the rate of technical substitution between radio spectrum and another input such that the quantity of output produced by a firm using radio spectrum is assumed to be constant. In other words, if the value of the input, say labour, is paid X dollars per unit of time, we could ask how much extra labour would be required to maintain output constant if the amount of spectrum is reduced by say 1 MHz. As the price of labour is determined on a competitive market, this approach identifies the value of spectrum at the margin in term of other commodities bought and sold on markets.

One of the strong appeals of the Smith-NERA least-cost alternative method is its simplicity. Furthermore, applied correctly it permits the promotion of productive efficiency. In this section the method is illustrated and its application demonstrated.

Applying the Smith-NERA Method

Suppose firm *i* in sector *j* which uses spectrum s_{ji} and another input (say base stations b_{ij}) produces output q_{ji}. The firm's output can be expressed as:

$$q_{ji} = f(b_{ij}, s_{ji}) \qquad (1)$$

Assume the firm maximizes profit and hence minimizes its costs. If a unit of spectrum Δs is added to or subtracted from s_{ji}, a compensating change could be made in the amount of the other input b_{ji} such that total output is unchanged at q_{ji}. By doing this the rate of 'technical substitution' between the two inputs can be assessed. For a $\Delta s=1$ there would be an implied change Δb, and where the latter is multiplied by its price (which is determined on a competitive market) this allows for a monetary representation of the rate of substitution. By applying the same procedure in other sectors, comparisons can be made across sectors using the common unit money (which means comparisons can be made across sectors where different inputs substitute for spectrum).

In Table 1 below we present a hypothetical example illustrating the Smith-NERA least cost alternative method. The values in the cells are calculated as described in the preceding paragraph. Hence, 100 in use I, frequency band *a* is the value, expressed in money terms using the least-cost-alternative input, of the marginal unit of spectrum. For example, a

8 Para. 22, page 7, [2].

unit of spectrum may be worth four base stations which each have a price 25. The values in the other cells also represent the value of a marginal unit of spectrum. For productive efficiency to be satisfied, spectrum ought to be allocated across uses so that these values are identical. It can be seen in the table that they are not equal. The example is an illustration of productive inefficiency.[9]

Table 1

	Frequency bands			
Uses	a	b	c	Non radio spectrum input
I	100	75	0	0
II	35	60	30	0
III	10	10	15	5

Further application of the Smith-NERA method leads to recommended prices for radio spectrum consistent with productive efficiency.

Consider the values in the row associated with Use I. The marginal value of frequency band *a* in Use I is 100 and the marginal value of frequency band *b* in Use I is 75. Note that frequency band *b* is an imperfect substitute for frequency band *a* in Use I. However, the marginal value of frequency band *b* in Use II is 60. Society would be better off therefore if some of frequency band *b* were re-allocated to Use I. This is because a marginal unit of frequency band *b* applied to Use I could produce the same output in Use I while freeing up enough resources to compensate Use II (and hence maintain a constant output in Use II) and provide some extra resources for additional production in the economy.

The above can be stated in terms of opportunity costs. The opportunity cost of frequency band *b* spectrum in Use II is 75, the foregone saving in terms of least-cost-alternatives that would arise if the frequency band were used in Use I (the next best alternative). By expressing the value of marginal spectrum in terms of opportunity cost, it is possible to address the issue of pricing radio spectrum.

What should the administrative price be for radio spectrum frequency band b? This is determined by permitting variation in the frequency bands allocated to the three uses. It is clear that more of frequency band *b* ought to be allocated to Use I, and more frequency band *c* should be allocated to Use II.

CONCLUSION

The Smith-NERA least-cost-alternative method provides a relatively simple tool for identifying value ranges which can be used to guide the setting of administrative prices for radio spectrum. The prices established accord with the principle of opportunity cost and are consistent with the objective of achieving efficiency (in particular, productive efficiency).

REFERENCES

[1] Faulhaber, Gerald R. and David Farber (2002) “Spectrum management: property rights, markets, and the commons”, mimeo, University of Pennsylvania.

[2] Cave, Martin (2002) Review of Radio Spectrum Management, for Department of Trade and Industry and H M Treasury, March.

[3] Diamond, Peter and James Mirrlees (1971) “Optimal taxation and public production 1: Production efficiency and 2: Tax rules”, *American Economic Review*, 61, 8-27 and 261-78.

[4] Smith-NERA (1996) “Study into the use of spectrum pricing”, report for the Radiocommunications Agency by NERA and Smith System Engineering, April.

9 If re-allocation of radio spectrum were not possible, then the values in Table 1 could be compatible with productive efficiency. In particular, if firms in each use area differ and the values in the cells represent averages, then productive efficiency would be achieved in each use area if the price of spectrum were set equal to the identified opportunity cost.