AN ECONOMIC STUDY TO REVIEW SPECTRUM PRICING

INDEPEN, AEGIS SYSTEMS AND WARWICK BUSINESS SCHOOL

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Indepen Diespeker Wharf 38 Graham Street London N1 8JX

Telephone +44 (0) 20 7324 1800 Facsimile +44 (0) 20 7704 0872 http://www.indepen.co.uk

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Project Team:

Phillipa Marks (Indepen)

Brian Williamson (Indepen)

John Burns (Aegis)

Chris Doyle (Warwick Business School)

Professor Martin Cave (Warwick Business School)

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Summary

1 Introduction

This is the final report for a study for the Radiocommunications Agency (RA) to review the application of administered incentive prices (AIP) to radio spectrum. The terms of reference are reproduced in Annex 1. A summary of the scope of the work covered is as follows:

- Advise whether the existing methodology for calculating administered incentive prices (AIP) generates optimal incentives for licensees to use spectrum efficiently. If not, develop a new methodology that is economically robust and can be implemented in practice;
- Advise on whether and under what circumstances AIP would be charged to licensees with tradable licences;
- Recommend a list of uses that will be used to demonstrate what illustrative charges would be under the new AIP methodology;
- Advise on the relevant objectives for sound broadcasting and the extent to which incentive pricing would be appropriate given broadcasting policy constraints;
- Develop illustrative charges under the proposed AIP methodology and undertake sensitivity analysis on key variables used to estimate charges;
- Recommend a practical approach to setting AIP in bands for which the methodology cannot be practically applied;
- Develop principles that can be applied to identify those areas of the spectrum that are not suitable for the application of AIP and recommend a pricing approach in these cases; and
- Develop a methodology which will allow the effectiveness of the proposed pricing approach to be monitored and tested and provide a practical implementation of the testing methodology.

For clarity the following definitions are used throughout this report:

- Administered incentive prices (AIP): prices charged to spectrum licensees (and holders of recognised spectrum access (RSA)) that are set by the regulator and are intended to reflect the opportunity cost of spectrum use (and thereby provide effective incentives for efficient use of spectrum);
- Administrative charges: charges to spectrum licensees (and holders of RSA) that are set by the regulator and are intended to recover the regulator's administrative costs incurred in spectrum management, control and enforcement;
- Marginal opportunity cost refers to the opportunity cost calculated at the margin by looking at how input substitutability varies in response to changes in spectrum.[1]
- The report uses the terms marginal benefit and marginal opportunity cost somewhat interchangeably.[2]

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[1] This means that we have looked at the marginal rate of technical substitution – and in that sense our value could be viewed as the marginal "technical" opportunity cost derived from firms' production functions.

- Spectrum trading: licensees may transfer some or all of their spectrum rights and obligations to another entity.

2 Context

AIP were introduced in 1998 under the Wireless Telegraphy Act with the objective of promoting greater efficiency in the use of spectrum. The prices set were based on the value of the next best alternative using a method developed by Smith-NERA in 1996.[3] In 2002, the Independent Spectrum Review[4] recommended that spectrum prices should be set on the basis of opportunity cost and noted that existing prices could be below this level. The Government has endorsed the use of opportunity cost pricing and has proposed that the approach to setting AIP should be reviewed.[5] This study represents a contribution to that review.

The study's recommendations must be consistent with the framework for spectrum management contained in the recent package of EC Communications Directives and in the Communications Act 2003. In particular the Framework Directive (Article 9) allows for the transfer of rights and the Authorisation Directive imposes conditions on administrative charges (Article 12) and fees for rights of use (i.e. AIP) for radio frequencies which reflect the need to ensure optimal use (Article 13)[6]. The Communications Act contains provisions that define the objectives of spectrum management, allow spectrum trading, introduce RSA and separately identify AIP and administrative charges.

Finally, the Government consulted on proposals for spectrum trading and RSA in 2002. Issues such as whether licensees with tradable licences should pay AIP and whether AIP should apply to operators with RSA are addressed in this study.

3 The economics of spectrum

The total supply of spectrum is fixed, but technology affects the extent to which it can be utilised. In terms of the efficient use of spectrum, we are concerned with two separate issues. First, the assignment of spectrum rights within a particular frequency band. Second, the allocation of spectrum to categories of use. AIP can influence both assignment and allocation, though in practice there is likely to be much greater discretion over the assignment of rights in the short to medium term, as international agreements may constrain spectrum allocations.

For some spectrum uses, such as cellular telephony, demand has grown significantly over the past two decades. There is now excess demand in a number of spectrum bands, and the value of spectrum to uses in the same or potentially substitutable bands may differ

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[2] At the social optimum marginal technical opportunity cost and marginal value would be the same, away from the optimum they will differ, but marginal technical opportunity cost values are both more practical to calculate and provide a narrower bound on the marginal value which should inform decisions over pricing that would shift spectrum use towards a social optimum. We do not discuss alternatives to the marginal cost/value methodology we propose since in general alternatives would not be consistent with the requirement in the terms of reference to "…generate incentives that promote the economically efficient use of the radio spectrum."

[3] Study into the Use of Spectrum Pricing, NERA and Smith System Engineering, Radiocommunications Agency, April 1996.

[4] Review of Radio Spectrum Management, Professor Martin Cave, for Department of Trade and Industry and Her Majesty's Treasury, March 2002.

[5] Government Response to the Independent Review of Spectrum Management, Department of Trade and Industry and Her Majesty's Treasury, October 2002.

[6] Directive 2002/21/EC, on a common regulatory framework for electronic communications networks and services, OJ L 108; Directive 2002/20/EC, on the authorisation of electronic communications networks and services, OJ L 108.

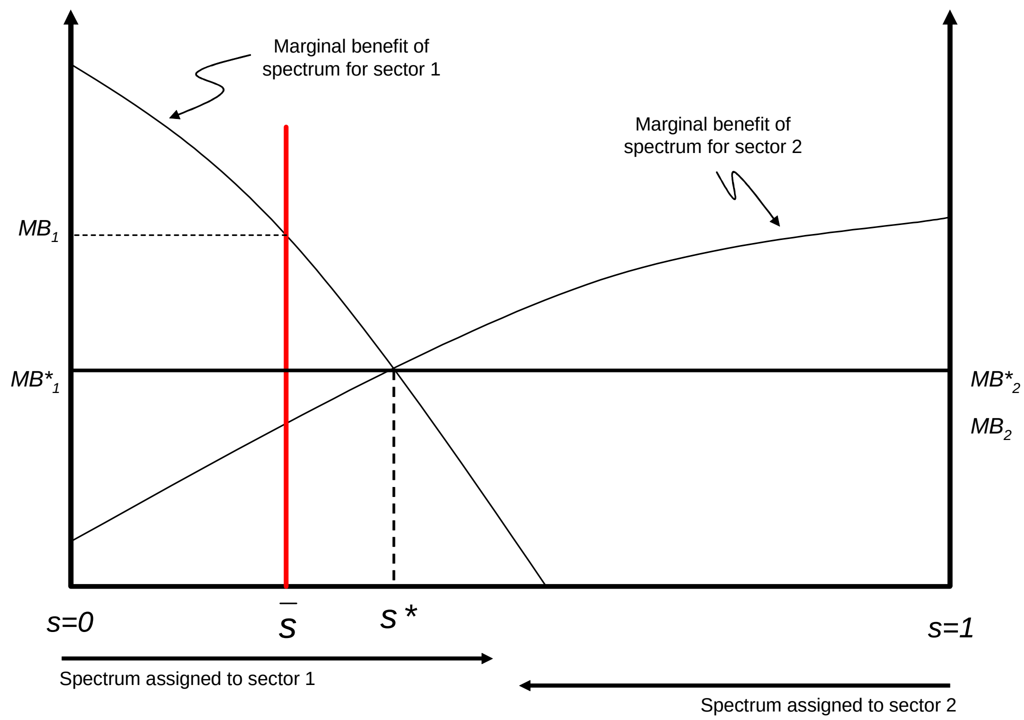
considerably. There are therefore potential gains in efficiency where a high value use can be substituted for a lower valued use of spectrum.

4 The economics of spectrum pricing

The setting of spectrum prices ought to be consistent with efficiency and consequently enable the maximization of total welfare or surplus, leading to what may be termed the social optimum.

Spectrum is an input, and in a competitive economy the use of inputs is efficient where marginal rates of substitution are equal across all the firms using the input. In the absence of constraints on spectrum use and where spectrum is regarded as homogeneous, efficiency is attained when the value of spectrum to society at the margin is equal across different users and uses. In other words, we should not be able to re-allocate spectrum to bring about an improvement in welfare without harming the welfare of another user. This is illustrated in Figure 1:

Figure 1: Demand for competing uses of spectrum



A price for spectrum that would achieve an efficient allocation is the price that equates the marginal benefits of spectrum in sectors 1 and 2 i.e. the value at S*. The vertical solid line shows the existing inefficient allocation of spectrum. At this allocation the marginal benefit of spectrum in use 1 exceeds that in use 2 and overall efficiency could be improved by allocating more spectrum to sector 1 and less spectrum to sector 2. The setting of spectrum prices can aid the achievement of efficiency by providing incentives for reallocations to occur.

5 The Smith-NERA methodology

Smith-NERA proposed a method for evaluating AIP based on opportunity costs. The approach focused primarily on re-assigning spectrum from low to high value users within frequency bands. Marginal opportunity costs were calculated for frequency bands used by mobile services and fixed links.

In addition, Smith-NERA suggested that mobile and fixed link prices could be used to set benchmark prices for spectrum that could in principle be used by mobile or fixed link services respectively. As a general rule mobile prices were applied below 2GHz while fixed link prices were applied above 2GHz.

Marginal opportunity costs were estimated by calculating the impact of a hypothetical marginal change in spectrum on the costs of an "average firm", assuming the level of output and service quality were unchanged.[7] Hence, spectrum value is assessed at the margin by using the opportunity cost of alternative inputs.

The extension of mobile and fixed link prices to other spectrum bands/uses introduced incentives to reassign spectrum among uses. However, the approach did not allow for the possibility that the reallocation of spectrum towards a more efficient allocation would change the marginal value of spectrum in different uses e.g. if cellular mobile were to be allocated more spectrum, its value of spectrum at the margin would probably decrease as output produced would change.

The actual application of AIP following Smith-NERA resulted in lower prices than those proposed. The government set the prices below the estimated values (by at least 50%), and the estimated values were modified further to take account of other factors (usually in a downwards direction).

6 Proposed approach to spectrum pricing

Our proposed approach explicitly recognises that AIP calculated away from an efficient point does not represent the opportunity cost of spectrum at the optimum, and that the opportunity cost at the optimum will lie between values calculated for alternative uses/users. Once AIP are implemented they will result in changes in spectrum use and spectrum assignment over time. Periodic recalculation of AIP is therefore required to ensure convergence towards the optimum.

The underlying methodology used to calculate the opportunity cost of spectrum, given the current allocation to different uses, follows the Smith-NERA least cost-alternative method. We reviewed the method and concluded that it was the best feasible methodology consistent with achieving a social optimum over time. Our method takes the status quo as a starting point for calculating marginal opportunity cost, and relies on iteration to achieve a closer approximation to the social optimum over time. We consider this superior to any attempt to estimate the social optimum directly based on a hypothetical estimate of marginal costs and benefits at the (unknown) optimum.

In an extension of Smith-NERA values are calculated for a wider range of uses and bands. These are then used to populate a matrix, as illustrated in Table 1. In this example, frequency band a is used by Use I, frequency band b is used by Use II and frequency band c is used by Use III. The marginal values for the existing uses are shown in bold.

[7] Maintaining output constant allows the focus to be on productive efficiency.

Table 1: Estimated marginal benefits

Uses	Frequency bands a	b	c
I	100	75	0
II	35	60	30
III	10	10	15

The matrix informs us, for example, that at the margin frequency band b is more valuable to society in Use I than in Use II, though frequency band b is less valuable to Use I than frequency band a. Hence there ought to be a movement of frequency band b spectrum from Use II to Use I. In the example, the marginal opportunity cost of frequency band b should lie between 75 and 60. Note that basing AIP on this could also have the effect of re-assigning spectrum from low to high value users in band b.

Judgement is needed with respect to the actual marginal opportunity cost chosen in the interval. It is more efficient to err on the side of caution to ensure that overall spectrum is not left idle. After a period of time the values in the matrix would be re-calculated, and further AIP derived, providing incentives to move over time to an efficient allocation recognising that changes in technology and tastes will probably result in efficient allocations shifting through time.

7 Trading and AIP

The Independent Spectrum Review proposed that existing licenses should be modified to enable spectrum trading, and in its response to the Review the Government stated “We will comprehensively review the current pricing methodology, re-examine licence conditions to remove any unnecessary restrictions and introduce spectrum trading”. We consider the possible interactions between the policy instruments.

Based on static analysis both spectrum pricing and trading could in principle lead to identical, and efficient, outcomes. However, what advantages, if any, might AIP confer alongside trading? And, what implications does trading have for the appropriate level of AIP?

AIP might promote efficiency more effectively than trading where government or other not-for-profit entities are important spectrum users, since such agencies may be more responsive to an actual cost (with AIP) than an opportunity cost (with trading), as cost minimisation is likely to be an important objective for these entities. AIP could also promote efficiency more effectively where trading may be slow to emerge, or where the best way to define the rights to be traded is unclear. However, trading avoids the need and hence costs associated with identifying AIP, and may be dynamically superior since prices can evolve in response to expected changes in technology and preferences.

AIP and spectrum trading can be applied simultaneously to the same frequency band. If the AIP is set at a level below the value that would equate supply and demand in a spectrum traded market, then trading is not distorted and efficiency ought to be achieved. If, on the other hand, the AIP were set too high there is likely to be no trade and efficiency would be unlikely to be achieved. There is therefore even greater reason to err on the side of caution in setting AIP where spectrum trading is also present. In this case, AIP are assumed to be calculated independently of observed traded prices.

What if instead AIP are set taking into account traded prices? If AIP were linked too directly to observed trading prices, this could discourage both trade and innovation. To minimise disincentives to trade and innovate one option is to commit to only using information from trading with a lag in setting administered prices. In practice this may result from the necessary administrative lag in resetting AIP.

8 Uses subject to AIP

In deciding the frequency bands and services which should be subject to AIP the following tests were applied:

1. Is there excess demand for spectrum now or in the near future from existing uses?
2. Can the spectrum be used for another purpose and, if so, is there excess demand from other uses?
3. Is it practically feasible to collect AIP fees given possible constraints due to avoidance or illegal use?
4. Are there any policy or political factors that prohibit the use of AIP?

Table 2 below summarises the conclusions for those services to which AIP should be applied. The conclusions align with those reached by the Independent Spectrum Review. In cases where AIP is not appropriate, because the marginal opportunity cost of spectrum is zero, it is proposed that licence fees should be set only to reflect the spectrum management and enforcement costs caused by each service.

9 Applying spectrum pricing

Marginal values and AIP are calculated according to the following steps:

1. For a given frequency band identify the current and other potential uses. These uses may be variants of the same allocation category (e.g. PMR and cellular mobile) or alternative allocations such as broadcasting and fixed link services.

2. Calculate the marginal private value (i.e. opportunity cost) of spectrum for the current use of the band and other uses until a use is found which has a higher marginal value than the current use.

3. If there is a use with a marginal private value higher than the current use then set the AIP between the two values, but towards the bottom end of the range.

4. If there is no use with a marginal private value higher than the current use of the band then set the AIP at the marginal value for the current use.

Externalities, other market failures and specific policy objectives should be achieved through other instruments (e.g. interference management, price and other regulation and state funding). This is desirable on efficiency grounds.

It is important to note that the marginal opportunity cost values reported below are calculated for illustrative purposes only, so as to demonstrate how the recommended methodology can be applied. The information used to estimate illustrative values was drawn from publicly available sources and our previous experience.

Table 2: Summary of Conclusions on Applying Administrative Incentive Pricing

Service	Excess demand – existing use	Demand from alternative uses	Can the spectrum be used for another purpose?	Policy or practical impediments	Suitable for pricing
Aeronautical communication	Yes in 118-137 MHz band	Generally no	Some limited scope for other aeronautical services (radiolocation or navigation)	International bands	Yes in 118-137 MHz band
Aeronautical radar	Probably not currently but may be in future	In some bands (e.g. UHF Ch 36)	Yes (UHF Ch 36 for broadcasting and other spectrum for PMSE / ENG)	International bands in most cases (does not apply to UHF Ch 36)	Yes in UK-only allocations. Differential pricing to reflect out of band interference.
Broadcasting – TV	Yes	Yes (e.g. mobile or broadcast data applications and PMSE)	Yes in longer term – analogue TV. Yes- digital TV	Broadcasting policy; European TV plan	Yes, to promote switchover after 2006 and efficient spectrum use after 2010
Broadcasting – sound	Yes – analogue And digital in some locations	Limited - analogue. Potential PMR/PAMR demand (Band III) or S-DAB (L-band)– digital	Yes, limited in practice esp. in analogue bands, due to international allocations	Licence conditions for commercial operators; policy for the BBC	Yes, once licensees have possibility of changing spectrum use
Defence	Probably not	In some bands (some already shared geographically)	Yes, except most NATO allocations	NATO allocations	Yes, except NATO bands
Fixed links	Yes (in some bands &locations)	No	Yes	No	Yes
FWA	Not in near term	Yes (mainly fixed links)	Yes	Yes, Broadband Britain agenda	Yes
Scanning Telemetry	No	Yes (PMR / PAMR)	Yes	No	Yes
Maritime communication	Yes, in certain bands and areas (e.g. VHF on south coast)	Yes in some bands – PMR in business maritime bands	Yes, except for internationally agreed channels	Certain channels allocated internationally for safety	Yes, for maritime business radio

Service	Excess demand – existing use	Demand from alternative uses	Can the spectrum be used for another purpose?	Policy or practical impediments	Suitable for pricing
Maritime radar	Probably not	Unlikely – international allocations or unsuitable for other uses	Limited - international bands	International bands	No except for differential pricing to reflect out of band interference
PMSE	Yes	Yes	Yes	No	Yes
PMR	Yes (in some bands and areas)	Yes in some bands (e.g. PAMR)	Yes (for some bands)	No	Yes
Public Safety	Not currently (TETRA is now available), potentially in longer term	Yes	Yes (e.g. migration to Airwave TETRA network)	Certain users reluctant to migrate	Yes (except possibly Airwave network – sharing NATO spectrum)
Public Mobile Networks	Yes for cellular & PAMR, CBS in certain bands / areas. No for paging, mobile data.	Yes (e.g. other mobile uses)	Yes, in most bands	International obligations (e.g. GSM Directive)	Yes
Satellite	No, except possibly L Band mobile services	Yes (in bands shared with fixed links)	Yes, except in internationally designated exclusive bands	RSA in some cases. “Free rider” issue.	Yes, shared bands only (requires RSA for downlinks).
Science services	No	Yes in non-exclusive bands (e.g. TV channel 38)	Yes, except in internationally designated exclusive bands	Needs RSA	Yes, with RSA (except internationally allocated exclusive bands)

Marginal values are calculated using the approach developed by Smith-NERA[8], namely the marginal value of spectrum is the additional cost (or cost saving) to an average or reasonably efficient user as a result of being denied access to a small amount of spectrum (or being given access to an additional small amount of spectrum). The additional cost (or cost saving) depends on the application and is calculated as the estimated minimum cost of the alternative actions facing the user. These alternatives may include

- investing in more/less network infrastructure to achieve the same quantity and quality of output with less/more spectrum;
- adopting narrower bandwidth equipment;
- switching to an alternative band;
- switching to an alternative service (e.g. a public service rather than private communications) or technology (e.g. fibre or leased line rather than fixed radio link).

This approach overstates the marginal opportunity cost of spectrum for reductions in spectrum and understates the value for increases in spectrum. An average of the values obtained from an increase and a decrease in spectrum gives a reasonable approximation to the marginal value. In practice, it has not always been feasible to estimate values for increases and decreases in spectrum.

The approach assumes that the quantity and quality of output produced by the use remains constant. This may also lead to some bias in the estimated values, however, we conclude that it is not practical to take into account the impact of quantity or quality changes.

10 Fixed services

Marginal opportunity costs for fixed links, fixed wireless access (FWA) and fixed satellite services have been estimated. These are shown on a common basis for the 4GHz band in Table 3:

Table 3: Marginal opportunity costs for fixed services

Service	Fixed Links	FWA	Satellite
Marginal value per 2 x 1 MHz	£132 per link	£581 - £33,296 per base station sector	£28,000 per earth station
Marginal value per 2 x 1 MHz per km^2	£0.76	£0.82 - £47.10	£56

The methodology developed in this report proposes that AIP in shared bands or bands where spectrum could be reallocated between services should be set between the marginal opportunity cost for a current use and the next highest value. In this case, this would mean setting fees for satellite users near to or at the fixed link or FWA value. Given the uncertainty surrounding the FWA estimates[9] and that FWA spectrum can be used for fixed links we suggest the same value is applied to fixed link and FWA uses. If different values are to apply then the RA will need to use an administrative rule to ensure FWA bands are only used for

[8] Study into the Use of Spectrum Pricing, NERA and Smith System Engineering for the Radiocommunications Agency 1996.

[9] The uncertainty reflects the relative immaturity of the FWA market and the wide range of deployment scenarios and equipment costs that exists.

that purpose. We note that if government wishes to promote the deployment of FWA services, then it could consider the applicability of pricing to FWA or use instruments other than spectrum pricing to achieve this objective.

We have reviewed the RA's algorithms for fixed links and satellite services and have proposed a number of changes. For fixed links we recommend that:

- the regulator carries out an analysis of link capacity in specific bands and areas to ascertain the validity of the proposed pricing differentials for links of differing availability; and
- an equipment technology modifier is not appropriate, assuming that the bandwidth modifier is directly proportionate to bandwidth.

We recommend that the determination of the licence fee for fixed links in a congested area should be based on the following algorithm:

Fee = Marginal Value (£ per 2x1 MHz) x bandwidth (MHz) x path length modifier x frequency band modifier x antenna technology modifier x availability modifier

For fixed satellite services, we recommend that

- Fees are set taking account of the denial area of a typical satellite earth station.
- AIP is not applied in exclusive satellite bands, unless it is possible that the band might be shared with other fixed uses.
- Bands and geographic areas that are defined as congested are consistent with those defined as congested for fixed links and/or FWA use.

We recommend that AIP for scanning telemetry continue to be set on the basis of PMR values, given the similarity in the technology and frequency channelisation.

11 Mobile services

The marginal opportunity costs obtained in this study are shown together with the Smith-NERA values in Table 4. Cellular is the highest value use for the bands it occupies and so the AIP for these bands should be set at the cellular marginal value. For other mobile bands, PAMR and PMR services are generally substitutable in which case the AIP for each of these services should be set between the PMR and the PAMR values. If cellular services can also use these bands then values should be set towards the low end of the range between PMR and cellular values i.e. around £1.3m per 2x1MHz.

Table 4: Mobile Marginal Opportunity Cost for a 2x1MHz National Channel

	Smith-NERA (1996)	This study
Cellular – 900 MHz	£1.63m	£1.68m
Cellular - 1800 MHz	£0.81m	£1.68m
PAMR	£1.36m	£1.27m
PMR	£1.75m	£1.24m

In setting AIP for local / regional PMR services, we recommend that values are based on the share of the UK population in the area sterilised.[10] This avoids the need to define specific areas as congested or uncongested. We recommend that the regulator moves quickly to a situation where it can identify the area sterilised by a licensed PMR system and suggest that an appropriate criterion for defining this area would be the field strength contour currently applied to common base station services. By combining a population database with the RA's coverage planning tool, it will be possible to determine to a reasonable approximation the population residing within the area bounded by the field strength contour and to set a price accordingly.

In the case of shared PMR channels, we consider that the current approach based on defining broad user categories whose typical usage patterns can be determined from statistical measurement data provides an equitable and transparent means of apportioning fees to users of shared channels. We recommend that the basis for the current fees is reviewed using the regulator's monitoring data.

12 Broadcasting services

We have produced estimates of the marginal opportunity cost of TV spectrum. Marginal opportunity costs are estimated for analogue TV and digital TV after switchover using the standard marginal opportunity cost methodology set out in this report. This gives values of £1m/MHz and £1.2m/MHz respectively. The opportunity cost estimate for analogue transmissions assumes that if these transmissions are not available households would be supplied the five analogue channels over cable or satellite. In practice some households may be able to receive services over DTT and this may reduce our estimates. However, the estimates make no allowance for the loss of reception for second and third sets in each household, which would tend to increase the value.

An indication of the incentives to migrate to digital transmission is provided by estimating the cost of providing national coverage for the four analogue channels using either analogue or digital technology. With analogue 44 channels are required at 8MHz per channel, with an opportunity cost of £352 million per annum. With digital technology around 9 channels at 8MHz per channel would be required at an opportunity cost of £86.4 million per annum– a difference of £265.6 million per annum.

Lack of reliable data has meant that we have not been able to estimate marginal values for sound broadcasting using either the least cost alternative methodology or an approach based on station profitability.

13 Other services

Section 10 discusses the approach to deriving marginal opportunity cost and AIP for aeronautical services, defence, maritime communications, programme making and special events (PMSE) and science services.

It is recommended that AIP are applied to the VHF aeronautical communications band (118-137 MHz). Provisional estimates of marginal opportunity cost for this spectrum range from £11,700 to £41,200 per 25 kHz channel. It is suggested that AIP is applied to ground stations and that aircraft fees are also adjusted so that there is a premium for equipment using 25 kHz

[10] That is the area within which the spectrum is denied to other users.

channels based on the cost differential between narrowband and conventional (i.e. 25 kHz) equipment.

While there appears to be a good case for pricing use of spectrum by aeronautical radars in bands that are expected to become congested, we have not been able to obtain reliable information on radar costs and so have not been able to derive marginal opportunity costs. In the case of Channel 36, the AIP for TV broadcasters could be applied.

We recommend that congested maritime business communications bands should be priced based on the AIP for PMR; otherwise, maritime bands are exclusive, international allocations that are not currently considered to be congested.

For defence, PMSE and science services we recommend that above 3GHz the fixed link AIP are applied and below 3GHz either the AIP for mobile (PMR) or broadcasting services are applied depending on which of these services is expected to use the spectrum under consideration. AIP should only be applied in those bands where the fixed, mobile or broadcast use experiences congestion and where use of the spectrum by these services would be constrained by defence, PMSE or science service use. To avoid double counting in shared bands, the national AIP should be apportioned based on the share of bandwidth multiplied by the area sterilised.

14 Implementation issues

Implementation issues are discussed in Section 11. In summary we recommend that:

- New values for AIP are implemented with a short, if any, transition period, following appropriate consultation.
- AIP should be reviewed about every five years and the regulator should commit in advance to a well-defined review process.
- The regulator monitors the impact of pricing and reports evidence on the efficiency benefits achieved. Data that should be collected by the monitoring activity are specified.
- In uncongested locations, users should pay fees or administrative charges that are set at a level that recovers the variable costs incurred by the regulator It may be expedient to set these charges as a fraction of the AIP, but this link should not be perpetuated over time, as this could mean increasing fees when this is not justified on efficiency grounds.
- The regulator undertakes research aimed at producing information on users' willingness to pay for spectrum. This information could be used in both setting future values for AIP and more immediately for assessing the costs and benefits of AIP. The data should be collected on a more comprehensive basis than has been done previously and should be collected regularly, at least every five years, given that demand conditions may change over time.

1 Introduction

1.1 Scope of the work

This is the final report for a study for the Radiocommunications Agency to review the application of administrative incentive pricing. The scope of the work covered is as follows:

- Advise whether the existing methodology for calculating administered incentive prices (AIP) generates optimal incentives for licensees to use spectrum efficiently. If not, develop a new methodology that is economically robust and can be implemented in practice;
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- Develop a methodology which will allow the effectiveness of the proposed pricing approach to be monitored and tested and provide a practical implementation of the testing methodology.

It is important to note that the marginal values and AIP reported below are calculated for illustrative purposes only, so as to demonstrate how the recommended methodology can be applied. The information used to estimate illustrative values was drawn from publicly available sources and our previous experience.

For clarity the following definitions are used throughout this report:

- Administered incentive prices (AIP): prices charged to spectrum licensees (and holders of recognised spectrum access (RSA)) that are set by the regulator and are intended to reflect the opportunity cost of spectrum use (and thereby provide effective incentives for efficient use of spectrum);
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[11] This means that we have looked at the marginal rate of technical substitution – and in that sense our value could be viewed as the marginal "technical" opportunity cost derived from firms' production functions.

- The report uses the terms marginal benefit and marginal opportunity cost somewhat interchangeably; and[12]
- Spectrum trading: refers to the situation where licensees may transfer some or all of their licence rights and obligations to another entity.

1.2 Context

AIP were introduced in 1998 under the Wireless Telegraphy Act with the objective of promoting greater efficiency in the use of spectrum. The prices set were based on the value of the next best alternative using a method developed by Smith-NERA in 1996.[13] In 2002, the Independent Spectrum Review[14] recommended that spectrum prices should be set on the basis of opportunity cost and noted that existing prices could be below this level. The Government has endorsed the use of opportunity cost pricing and has proposed that the approach to setting administrative incentive pricing should be reviewed.[15] This study is a contribution to that review.

The study's recommendations must be consistent with the framework for spectrum management contained in the recent package of EC Communications Directives and in the Communications Act. In particular the Framework Directive (Article 9) allows for the transfer of rights and the Authorisation Directive imposes conditions on administrative charges (Article 12) and fees for rights of use (i.e. AIP) for radio frequencies which reflect the need to ensure optimal use (Article 13). The Communications Act contains provisions that define the objectives of spectrum management, allow spectrum trading, introduce RSA and separately identify AIP and administrative charges.

Finally, the Government consulted on proposals for spectrum trading and recognised spectrum access in 2002. Issues such as whether licensees with tradable licences should pay AIP and whether AIP should apply to operators with RSA are addressed in this study.

1.3 Report structure

The remainder of this report is structured as follows.

- Section 2 provides the economic framework used to analyse the existing and new pricing methods and importantly establishes the efficiency criteria that underpin the analysis.
- Section 3 assesses the Smith-NERA approach to setting AIP.
- Section 4 extends the Smith-NERA approach to address the issue of allocative efficiency and provides a recommended pricing methodology.

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[12] At the social optimum marginal technical opportunity cost and marginal value would be the same, away from the optimum they will differ, but marginal technical opportunity cost values are both more practical to calculate and provide a narrower bound on the marginal value which should inform decisions over pricing that would shift spectrum use towards a social optimum. We do not discuss alternatives to the marginal cost/value methodology we propose since in general alternatives would not be consistent with the requirement in the terms of reference to "…generate incentives that promote the economically efficient use of the radio spectrum."

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[14] Review of Radio Spectrum Management, Professor Martin Cave, for Department of Trade and Industry and Her Majesty's Treasury, March 2002

[15] Government Response to the Independent Review of Spectrum Management, Department of Trade and Industry and Her Majesty's Treasury, October 2002.

- Section 5 analyses the interaction between trading and AIP.
- Section 6 identifies uses to which AIP should be applied and discusses practical issues that arise in setting AIP.
- Sections 7 to 10 present estimated marginal values and discuss how these values might be used to set AIP for fixed, mobile, broadcasting and other services (i.e. aeronautical, defence, maritime, programme making and special events and science services) respectively.
- Section 11 discusses implementation issues that will need to be addressed by the regulator when setting AIP.

Annex 1 sets out the terms of reference. Annex 2 provides the background to our conclusions on the uses to which AIP should be applied. Details of the calculation of marginal opportunity costs are given in Annexes 3-10**.**

2 The Economics of Spectrum

2.1 Introduction

This section introduces and discusses economic concepts applied in subsequent chapters. Policy objectives, means to achieve objectives and spectrum characteristics are described. The supply of and demand for spectrum are described, and the role of competition and markets analysed within the context of economic efficiency.

2.2 The supply of spectrum

Spectrum is an intangible resource freely available to society; other resources are not required to produce spectrum. Capital and labour are needed to make use of spectrum, but on its own spectrum holds little or no value to society.

The frequency bands used for radio purposes currently extend from around 9 kHz up to around 3000 GHz.[16] The physical properties of spectrum are such that everybody has access, in principle, to radio-spectrum: it is a non-exhaustible common access resource.

The total supply of spectrum available for radio usage is fixed, but innovations affect the extent to which spectrum can be utilized. Frequency bands may possess physical properties favourable to specific applications, and some frequency bands suit specific applications because of international coordination. Consequently, spectrum is not homogeneous and in practice it is often viewed as heterogeneous.[17]

In the twentieth century many frequency bands were allocated to broad use categories, such as broadcasting, radio-astronomy, fixed wireless applications, etc., usually through international agreement. Changing the designation of spectrum use in a frequency band that has been allocated internationally can be very time consuming[18] It is government policy to aim for greater flexibility in the allocated use of bands.

Coordination at an international level also occurs to support the management of spectrum, such as minimizing interference between radio systems operating in neighbouring countries.[19] The UK is less exposed to international interference than countries on Continental Europe, but coordination is needed between the British, French and Irish authorities and in some cases with authorities elsewhere in Europe.

In the UK, as in many other countries, spectrum is owned by the state (it is a public resource (asset)) and leased under various terms to users. To prevent unauthorized use of spectrum, it has traditionally been managed centrally by government. The *raison d'etre* of government control stems from perceived market failures associated with its common access and externality properties.

Access to frequencies is managed by government, either directly or through agencies. Access to a few frequency ranges is subject to light regulation (such as licence exempt

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[16] See *Strategy for the Future use of the Radio Spectrum in the UK*, Radiocommunications Agency, April 2002. In practice spectrum has been allocated up to 300 GHz.

[17] In this regard spectrum is no different to land.

[18] These changes are time consuming because they may require changes to international regulations governing spectrum use (e.g. the ITU Radio Regulations) and incumbent users may need to be migrated in order to accommodate a new use. Incumbents may be given notice periods of up to seven years.

[19] Interference between radio transmissions can often render systems inoperable. Spectrum use can therefore give rise to externalities.

frequencies) and in this case the spectrum is akin to the commons i.e. there is open access to the available resource, with limited restrictions on emissions and no protection from other users. Access to most frequency ranges, however, is closely regulated and in some cases frequencies are assigned to specific users on an exclusive basis. In other frequency ranges access rights are assigned on a shared basis (e.g. shared PMR channels).

In the short- to medium-term (typically up to 10 years), government has much greater discretion over the assignment of spectrum rights than over the allocation of spectrum (or frequency ranges) to categories of use. In the long-term (typically 10 years or more), government has some discretion to affect the allocation of spectrum to particular uses. This difference in discretionary powers has an important bearing on the supply-side of spectrum management policy.

2.3 The demand for spectrum

The demand for spectrum is derived from the demand for final goods and services that are produced using radio as an input. There are many different users of spectrum supplying these final goods and services (e.g. broadcasters, telephone companies, aeronautical users, taxi-firms, scientists, the military, etc.).

An important component driving spectrum demand is therefore the scale of demand for services which require radio spectrum in order to be produced. For some spectrum uses, such as cellular telephony, demand has grown significantly over the last 15 years leading to a corresponding increase in the demand for spectrum. There has also been a huge increase in spectrum use and demand at a domestic level (e.g. microwave ovens, car key fobs, TV and video remote controls and in-home wireless networks). Allocation policy has traditionally directed spectrum to uses taking account of likely demands.

In some frequency bands there is keen competition among users (actual and prospective) for spectrum rights, whereas in other frequency bands there is little or no congestion. Assignment policy, which is concerned with deciding who should use spectrum in a frequency band, has a role to play where demand is high relative to supply. Ideally spectrum ought to be assigned to users who contribute the most in terms of benefits to society. However, assignment policy is made complicated by: supply-side constraints (as discussed above), uncertainty, imperfect information, and changing demands for final goods and services.

If access to spectrum rights commands a usage fee (i.e. such as AIP), then the responsiveness of spectrum demand to changes in the usage fee (known as the own price elasticity of demand for spectrum) will depend on production technologies and on the nature of demands for final goods and services.[20] In many cases the demand for spectrum will increase as its price falls. The tendency for demand to increase as its price falls arises because users find it more profitable to substitute away from more expensive inputs.

The relationship between the demand for spectrum and its own price also reflects users' willingness to pay for spectrum. In many cases some users value spectrum relatively highly, particularly where final goods and services are similarly in high demand and there are few, if any, substitutes available for spectrum. Other users place a relatively low value on spectrum,

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[20] The variables affecting the elasticity of demand for an input were first described by Alfred Marshall (1920) *Principles of Economics*, 8th Edition London: Macmillan and formally stated by Hicks (1963) *The Theory of Wages*, London: Macmillan. An elegant presentation can be found in Christian Ewerhart (2003) "A short and intuitive proof of Marshall's Rule", University of Mannheim Department of Economics, mimeo, June 2003.

especially if alternative inputs with relatively low prices are a good substitute for spectrum in production.

The demand for spectrum is also affected by innovation. If innovation enables radio frequencies to be used more effectively in production of final services, this may lead to a lower demand for spectrum where demand for the final service is not very responsive to changes in price. On the other hand, if innovations bring about significant reductions in the costs of producing the final service, demand for spectrum may increase where the demand for the final service is highly responsive to price changes.

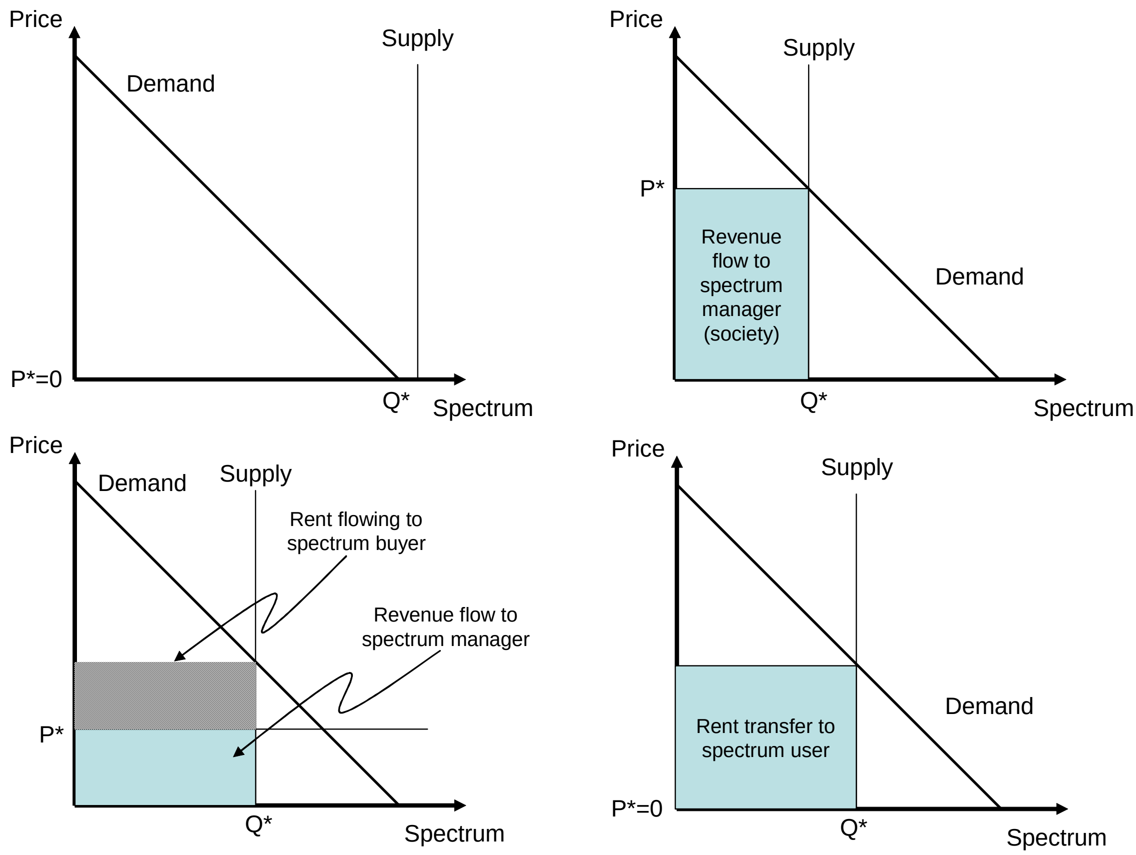
2.4 Spectrum markets: the interaction of supply and demand

In Figure 2.1 the demand and supply functions for spectrum are shown. It can be seen that the demand for spectrum increases as the price of spectrum falls, whereas the supply of spectrum is invariant as its price changes and the supply function is shown as a vertical line.

Through time demand will likely shift as technologies and tastes change. For example, increased demand for cellular telephony services would lead to the demand functions shown in Figure 2.1 shifting rightwards. By contrast, it is conceivable that new digital broadcasting technologies may lead to a fall in the demand for spectrum, resulting in a leftwards shift in the demand curves in Figure 2.1.

In the long-term the supply of spectrum to support a use may change, reflecting changes in spectrum allocation. Where the supply of spectrum increases (decreases) in a use area, this would lead to a rightwards (leftwards) shift in the supply curves shown in Figure 2.1.

Figure 2.1 Demand and supply curves for spectrum



In the upper left hand quadrant of Figure 2.1 the supply of spectrum exceeds demand at all price levels. Historically many frequency ranges exhibited 'excess supply', and consequently assigning spectrum on a first-come, first-served basis seemed reasonable.

As the demand for spectrum has grown markedly over the last two decades, fewer frequency bands exhibit excess supply. More often demand is greater than available supply at a zero price or even non-zero price for spectrum. For prices where demand is greater than supply there is 'excess demand'. Excess demand for spectrum is possible in the other quadrants in Figure 2.1.

The prices that rule in the markets for many goods and services emerge spontaneously via the interaction of buyers (demand-side) and sellers (supply-side). Where excess supply exists, prices tend to fall, and where there is excess demand, prices tend to increase. An equilibrium price is such that supply is equal to demand. An equilibrium price P* is illustrated in the upper right hand quadrant of Figure 2.1.

Unlike in most markets, spectrum prices are determined via an administered process. As one of the purposes of administered incentive pricing is to ensure that supply and demand for spectrum are balanced, the operation of AIP ought to mimic what would emerge spontaneously through market interactions.

An administrator could achieve a balance between supply and demand by setting the price of spectrum equal to P* as shown in the upper right hand quadrant in Figure 2.1. The revenue raised (sometimes referred to as 'rent') would flow to the spectrum manager.

Before 1998 spectrum in the UK was not priced to reflect economic scarcity. Consequently spectrum rents were enjoyed by spectrum users, as prices were relatively low. This is shown in the lower quadrants of Figure 2.1.

2.5 Targets and instruments: efficiency and prices

The discussion in the previous section showed that by varying the price for spectrum demand varies. Where the price of spectrum can be varied by a spectrum manager, this effectively provides an 'instrument' of policy.[21] If policy is directed towards a 'target' of balancing demand and supply, then the spectrum price becomes an effective instrument.

More generally the target of spectrum policy can be summarised as the attainment of economic efficiency. For example, the Communications Act 2003 states that spectrum assignment policy should ensure:

> *"the efficient use in the United Kingdom of the electro-magnetic spectrum for wireless telegraphy"*[22]

The Communications Act 2003 also states that the regulator Ofcom should promote:

> *"Efficient management and use of the part of the electro-magnetic spectrum available for wireless telegraphy; the economic and other benefits that may arise from the use of wireless telegraphy; the development of innovative services; and competition in the provision of electronic communications services."*[23]

Efficiency as a target of policy is often interpreted as meaning outcomes that are consistent with the application of the Pareto criterion.[24] The Pareto criterion states that a policy outcome is efficient when it is not possible to improve the well-being of one individual in the economy without harming the well-being of at least one other individual in the economy.[25] The Pareto criterion is useful for assessing policy reform, in that a policy which moves an economy from a position of inefficiency to efficiency is clearly desirable.[26]

Economic efficiency can be viewed as having three dimensions. These dimensions relate to production, consumption and the use of resources over time:

- Productive Efficiency – production of goods and services ought to be undertaken at the lowest possible cost (cost is measured in terms of inputs);
- Allocative Efficiency – the mix of goods and services produced must be optimal in the sense that no other mix can increase the well-being of one economic agent without harming the well-being of another economic agent; and

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[21] Traditionally spectrum managers have used the amount of spectrum allocated to uses (the quantity variable) as a means to achieve objectives, rather than the price variable. Choosing quantities served well when there did not exist excess demand for spectrum. However, it is now recognized that use of the quantity variable is insufficiently flexible in an environment where excess demand and variable demands prevail.

[22] Communications Act 2003, para. 152 section 5.

[23] Communications Act 2003, para. 154 section 2.

[24] For a statement on the Pareto criterion see page 313 in Andreu Mas-Collel, Michael D. Whinston and Jerry R. Green *Microeconomic Theory* Oxford University Press 1995.

[25] The Pareto criterion means that economic outcomes (sometimes called states) can be compared without recourse to interpersonal comparisons of utility. Hence it is possible to compare two outcomes without comparing individuals' utilities.

[26] The Pareto criterion is neutral with regard to distribution.

- Dynamic Efficiency – resources are deployed in a way that encourages the most desirable level of research and development and innovation.

Economic analysis has identified the structural and behavioural characteristics of an economy that would give rise to efficiency.[27] These conditions give rise to what is termed 'perfect competition'. In a perfectly competitive market economy demand and supply are brought into equality by the workings of the price mechanism, and the prices established accurately reflect 'opportunity costs'.

In equilibrium in a perfectly competitive economy the price mechanism establishes relative prices such that the cost to society of producing X in terms of Y reflects consumers' willingness to pay for such a transformation (the opportunity cost).[28] This result is known as the First Fundamental Theorem of Welfare Economics,[29] and it is often used to lend support to the claim that competitive markets are desirable. The Second Fundamental Theorem of Welfare Economics states that any Pareto optimum can be attained in a competitive economy by using appropriate lump-sum transfers. In short, in a perfectly competitive economy where policy instruments are non-distorting, the 'first-best' welfare maximizing outcome can be achieved.

The knowledge that equilibrium prices are consistent with efficiency in a perfectly competitive market economy is a useful guide for policy. In the context of spectrum management, it suggests that choosing prices for spectrum which equate supply and demand is likely to be consistent with efficiency.

In practice real economies do not accord with the model of perfect competition. Even if real economies were to accord with perfect competition, the practical infeasibility of applying lump-sum transfers means that 'second-best' outcomes are only feasible. But according to the general theory of the second best (Lipsey and Lancaster (1956))[30], it is generally not desirable when designing policy to set prices (more generally policy instruments) at 'first-best' levels where distortions persist elsewhere in an economy.

The finding of Lipsey and Lancaster would suggest that striving for spectrum prices that accord with the first-best outcome would achieve a welfare level below that which could be achieved by setting prices away from first-best levels. However, according to Diamond and Mirrlees (1971)[31], in setting policy to maximize welfare in a second-best setting it is not desirable to tax the use of inputs. Indeed, the Diamond-Mirrlees result suggests that the use of inputs in a competitive economy should satisfy conditions necessary for productive efficiency.[32] The implication of the Diamond-Mirrlees finding for spectrum pricing policy is profound.

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[27] For a fuller discussion on efficiency and competitive markets see Mas-Collel *et al. op cit*.

[28] The consumer's willingness to pay is also measured in terms of the rate of exchange between X and Y.

[29] The First Fundamental Theorem of Welfare Economics states that a competitive equilibrium (a Walrasian equilibrium) is a Pareto optimum.

[30] See R.G. Lipsey and K. Lancaster (1956) "The general theory of the second best", *Review of Economic Studies*, vol. 24, pp. 11-32.

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

[32] Peter Hammond (2000) "Reassessing the Diamond-Mirrlees Efficiency Theorem", ch. 12 pp. 193-216 in *Incentives, Organization and Public Economics: Papers in Honour of Sir James Mirrlees*, edited by Peter J. Hammond and Graham D. Myles, Oxford University Press, has shown that the Diamond-Mirrlees result is more robust than is conventionally believed.

If competitive markets operate pervasively in an economy, government policy is directed towards the promotion of competition where possible and where desirable, and government uses tax instruments predominantly on final goods and services to achieve second-best welfare maximizing outcomes, then use of spectrum should satisfy conditions needed for productive efficiency. If the latter holds, according to Diamond-Mirrlees policy as a whole ought to be consistent with a second-best welfare maximum.

As a corollary therefore, setting prices for spectrum that promotes productive efficiency is desirable for efficiency more generally.[33]

2.6 Productive efficiency and the use of inputs

In the previous section it was been argued that the use of inputs, which includes radio spectrum, ought to satisfy the conditions of productive efficiency. In this section, using a simple example, the relationship between the use of spectrum and productive efficiency is shown. Identifying the conditions required for productive efficiency in spectrum use will be useful in assessing the design of optimal spectrum prices in Sections 3 and 4.

Assume spectrum lies on a line between zero and one (the unit interval $[0,1]$)) and that it is used in two sectors, 1 and 2, in the economy.[34] The sectors could represent broadcasting and telephony. To produce the final outputs in each sector, firms choose the inputs labour and spectrum.[35] We suppose that firms in each sector are identical.[36] The total amount of labour is fixed and equal to L, and the wage rate w is determined on a competitive market. We assume prices of <u>all</u> final outputs produced in the economy are determined in competitive markets. Spectrum, however, is allocated to each sector via an administrative process rather than via a market.[37]

For simplicity assume spectrum management costs are recovered by general taxation.[38] Let $\bar{s}$ be the amount of spectrum allocated to sector 1; and $1-\bar{s}$ is allocated to sector 2. Each firm in each sector maximizes profits and chooses an output level (and hence inputs labour and spectrum) to achieve this aim. Note that the firms face a spectrum constraint, but the marginal cost of spectrum is zero where the constraint is not binding. At the allocation $\bar{s}$ total output produced in sector 1 is denoted $Q_1(\bar{s})$ and output in sector 2 is $Q_2(\bar{s})$.

Given an administrative allocation $\bar{s}$, there are three possible scenarios with regard to spectrum:

1 Demand for spectrum in each sector is equal to spectrum supply in each sector;

2 Demand for spectrum is no greater than spectrum supply in each sector; and

[33] Radio spectrum is sometimes used in sectors where the final outputs give rise to externalities (either beneficial or adverse). Where this occurs, other instruments may be chosen by a policy maker to influence the quantity of the final outputs. For example, the size of the television licence fee affects the revenue obtained by the BBC, which in turn affects the amount of broadcasting it undertakes. The licence fee is therefore a policy instrument available to government to influence the scale of broadcasting output made by the BBC.

[34] Alternatively consider the assignment of frequencies within a band to two users.

[35] Assume that many other sectors exist in the economy, but these do not use spectrum as an input. However, the other sectors make use of labour and other inputs such as capital.

[36] This assumption is subsequently relaxed.

[37] The only market 'imperfection' is the absence of a market for spectrum.

[38] The taxation could be linear in form as in Diamond-Mirrlees.

3 Demand for spectrum in one or both sectors is greater than spectrum supply in one or both sectors.

Where excess demand for spectrum is absent, the economy must be at an efficient point (say a second-best welfare maximum). This is because firms using spectrum could not increase profits by substituting labour (or other inputs) with spectrum, for otherwise they would do so given the zero price of spectrum. Consequently, a small re-allocation of spectrum would not give rise to an efficiency gain.

From a policy perspective interest focuses on scenario 3 where demand for spectrum at a zero price exceeds the fixed spectrum supply in one or both sectors. As the quantity of spectrum is fixed and finite, excess demand in one or both sectors raises the issue of whether a re-allocation of spectrum could bring about efficiency gains.[39] Alternatively, could a reallocation of spectrum be able to free-up labour resources (the other input) without necessitating a reduction in the quantity of output produced in each sector? If the latter were possible, then the released labour resources imply that additional outputs could be produced and that the economy could be operating efficiently.[40]

To examine whether a re-allocation of spectrum could deliver efficiency gains (or whether the current use of inputs is consistent with productive efficiency), consider the effect of a hypothetical small change in spectrum allocation (a re-allocation). Assume, however, that labour resources are adjusted following the re-allocation of spectrum so that outputs are maintained at $Q_1(\bar{s})$ and $Q_2(\bar{s})$. The re-allocation is illustrated in Figure 2.2, which is an example of what economists call an Edgeworth box diagram. In the diagram labour and spectrum appear on the axes, and combinations of inputs that yield the same output level in each sector are shown as isoquants.

The isoquants for sector 1 are convex to the origin labelled Sector 1, and isoquants further away from this origin represent points of higher output. Isoquants for sector 2 are shown as convex to the opposite corner labelled Sector 2. If $\bar{s}$ of spectrum is allocated to sector 1 (and $1-\bar{s}$ of spectrum is therefore allocated to sector 2), suppose sector 1 uses l_1 units of labour and sector 2 uses l_2. At this combination of inputs, shown in Figure 2.2 as point b, production is inefficient – as a re-allocation of spectrum (and a consequent change in labour) can bring about a higher quantity of output in one sector, without impairing the quantity of output in the other sector.

Only where the isoquants in the two sectors are tangential to one another is efficiency in production satisfied (that is productive efficiency). The locus of tangencies in Figure 2.2 is usually called the efficiency or contract curve. The contract curve gives rise to output combinations that are efficient and lie on the production possibility or efficiency frontier, which is shown in Figure 2.3.

At the allocation $\bar{s}$ outputs in the two sectors are equivalent to point b in Figure 2.3, which lies inside the frontier and is inefficient. We can assess the extent of the inefficiency in terms of labour resources. Suppose that for a small increase (or decrease) in spectrum $\Delta\bar{s}$, sector

[39] Indeed, policy may be designed with the attainment of efficiency gains being the main objective – rather than the idea of a quantum leap to a second-best optimum. This would be a situation of choosing 'incremental' spectrum prices. See R. Guesnerie (1977) "On the direction of tax reforms", *Journal of Public Economics*, vol. 7, pp. 179-202.

[40] The economy would not be using resources in a way that is consistent with productive efficiency, or in other words it would be lying off the production possibility frontier. This is illustrated in Figure 2.3.

1 output $Q_1(\bar{s})$ can be produced using Δl_1 units less (or more) labour. Although spectrum does not command a price in this example, it is possible to infer the value of spectrum $\Delta\bar{s}$ in terms of the other input labour: $w\Delta l_1$. The same reasoning can be applied to sector 2, where the value of $\Delta\bar{s}$ is $w\Delta l_2$, when assessed at $Q_2(\bar{s})$. These values represent the opportunity cost of spectrum.

Figure 2.2 Edgeworth box with sectors 1 and 2

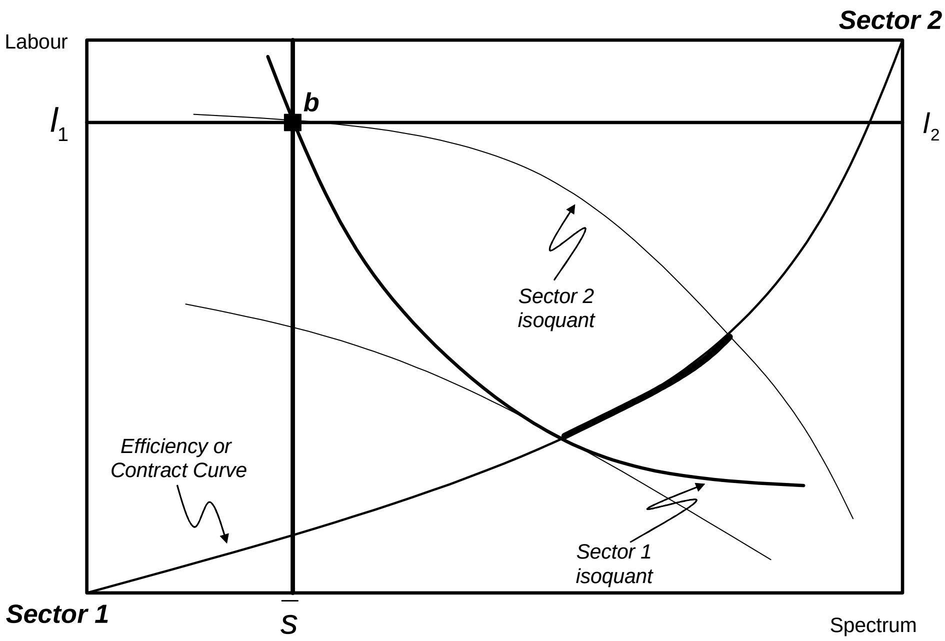
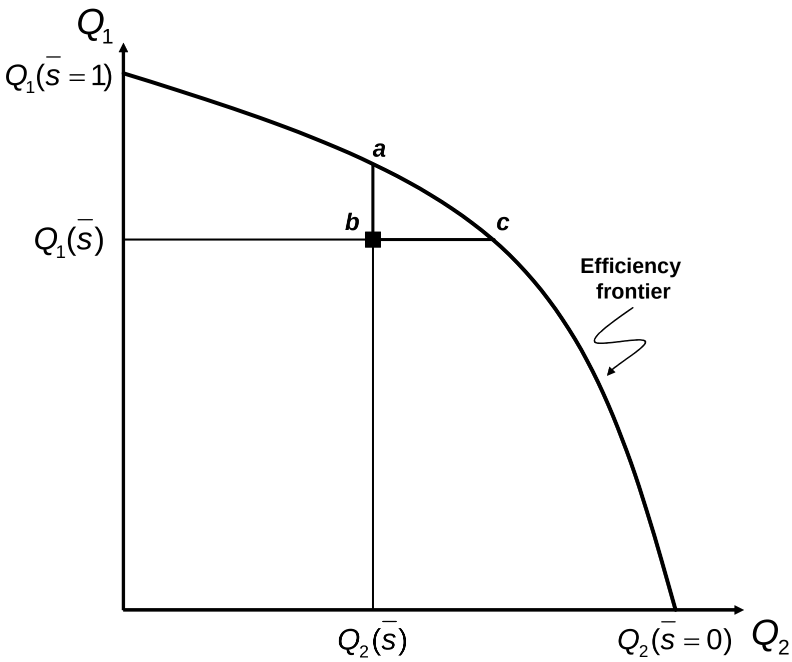


Figure 2.3 Efficiency frontier and spectrum allocation



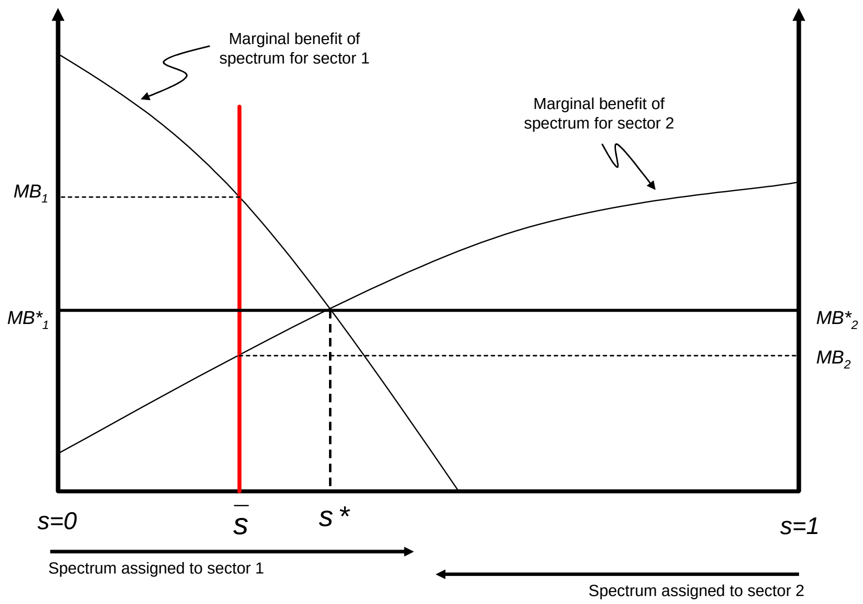
Where $\Delta\bar{s}$ is allocated to sector 1, the economy foregoes $w\Delta l_2$, which is the value of the input resources that would be saved by allocating $\Delta\bar{s}$ to sector 2 to maintain production at output level $Q_2(\bar{s})$. If the marginal unit of spectrum $\Delta\bar{s}$ were allocated to sector 2, by analogous reasoning the economy foregoes a saving worth $w\Delta l_1$ in sector 1.

As a spectrum manager can choose where to allocate the marginal unit of spectrum $\Delta\bar{s}$, it ought to allocate it to that sector where the saving is greatest. For example, if $\Delta l_1 > \Delta l_2$, then $\Delta\bar{s}$ ought to be allocated to sector 1 rather than sector 2. Furthermore, note that at any given output combination where $\Delta l_1 \neq \Delta l_2$, productive efficiency is not satisfied. Spectrum pricing policy ought therefore to be consistent with achieving equality in opportunity costs across different spectrum users and uses.

The values $w\Delta l_1$ and $w\Delta l_2$ can be interpreted as the marginal benefit of spectrum at the given output levels Q_1 and Q_2.[41] Assuming that there are decreasing returns to scale in each firm in each sector, the value of the marginal benefit in a sector declines as the use of spectrum increases.

In Figure 2.4 the marginal benefit functions are shown. As the amount of spectrum allocated to sector 1 increases, the marginal benefit of spectrum in sector 1 declines, whereas the marginal benefit in sector 2 increases. At the allocation $\bar{s}$ the marginal benefit of spectrum in sector 1 is greater than that in sector 2. As discussed above, the allocation shown at $\bar{s}$ is productively inefficient. It is only when the marginal benefit functions are equal that productive efficiency is satisfied, which is shown at the allocation s^* in Figure 2.4.

Figure 2.4 Marginal benefit functions for a given set of final outputs



[41] By assuming output as fixed, which is consistent with the application of the Pareto criterion, allocative efficiency cannot vary. Consequently any change to welfare derives solely from productive efficiency gains. Of course, by changing the amount of input in a sector there will be corresponding changes in the amount of the final output produced, which will have allocative efficiency effects.

2.7 Setting the correct prices for spectrum

Figure 2.4 provides an insight into the correct price to set for spectrum, where correct is interpreted as the price consistent with the attainment of productive efficiency. For the given output levels $Q_1(\bar{s})$ and $Q_2(\bar{s})$, the price which would direct firms in both sectors towards the productively efficient outcome is where the marginal benefit functions are equal; that is where $MB_1{*} = MB_2{*}$.

If a policy maker were to implement a spectrum price at $MB_1{*} = MB_2{*}$, then the resulting change in spectrum use in each sector would precipitate a change in outputs produced. This would lead to a shift in the marginal benefit functions and the spectrum price consistent with productive efficiency would change. The policy maker could revise the price of spectrum accordingly, and gradually the economy may converge to a second-best optimum.[42]

The above suggests that to implement correct or optimal spectrum prices in practice requires detailed information about the shape of the marginal benefit functions. While such information would be useful, it is extremely demanding to expect a spectrum manager to be able to ascertain it. As will be shown in Sections 3 and 4, however, it is not necessary to know in detail the entire marginal benefit functions in order to promote efficiency. Policy leading to greater efficiency can be devised using information about observed opportunity costs.

2.8 Concluding remarks

This section has established a theoretical foundation for analyzing the economics of spectrum pricing policy. At the core of the analysis is the Diamond-Mirrlees proposition that in a second-best economy the use of inputs must accord with the conditions needed for productive efficiency. The condition needed to be satisfied for productive efficiency was shown and this was related to the concept of opportunity cost. Assuming that markets and regulation operate to deliver efficiency elsewhere in an economy, achieving productive efficiency in spectrum use is therefore consistent with achieving overall efficiency in a second-best setting.

[42] The idea here shares a similarity to the general problem addressed in the optimal tax literature by Guesnerie (1975), *"Pareto Optimality in Non-Convex Economies", Econometrica, Vol. 43 (1) pp. 1-29*

3 The Smith-NERA method

3.1 Introduction

In this section the application of spectrum pricing in the UK is analysed in the context of the theoretical discussion in Section 2. Before 1998, spectrum charges were based on the administrative costs of managing spectrum. Since 1998 AIP have been applied to an increasing number of frequency bands. The justification for AIP and the implementation of AIP are described. Illustrative examples are used throughout.

3.2 AIP and opportunity costs

AIP were conceived as a means of promoting more efficient use of spectrum and the application of AIP was founded upon the principle of opportunity cost.

3.2.1 AIP in theory

Smith-NERA (1996) proposed a method for evaluating AIP based on marginal opportunity costs.[43] The approach focused primarily on assignment within frequency bands. Marginal opportunity costs were calculated for mobile services (i.e. PMR, PAMR and cellular services) and fixed links and were intended to result in a more efficient assignment of spectrum to these services. The allocation of spectrum to these services was assumed to be fixed.

In addition, Smith-NERA suggested that mobile and fixed link prices could in principle be used to set benchmark prices for other spectrum that could be used by either mobile or fixed link services respectively[44]. In these cases spectrum allocations were assumed to be flexible.

A hypothetical example is used to illustrate the Smith-NERA method. Assume radio spectrum is characterised as three frequency bands {*a*,*b*,*c*} in the interval [0,1]. Further assume there are three competing uses for radio spectrum: I, II and III. The allocation of spectrum is as follows: Use I is allocated frequency band a, Use II is allocated frequency band b, and Use III is allocated frequency band c.

In each Use area, users (firms) compete to provide final goods and services to consumers. Assume that the users differ in their abilities to produce final goods and services, with some users being more efficient than others.

The Smith-NERA approach first posed the question: what should be the price of spectrum to ensure an efficient assignment? Marginal opportunity costs were estimated by calculating the impact of a hypothetical marginal change in spectrum on the costs of an “average firm” assuming the level of output and service quality were kept constant.[45] For example, suppose a firm operating in Use I were provided an extra unit of spectrum. As outlined in the previous section (see Figure 2.4) the marginal benefit of spectrum would be declining at the fixed output level, and the marginal benefit would be equal to the cost savings the firm would enjoy were it to have the additional unit of spectrum.

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[43] See Annex 1 for a formal presentation of the discussion in this chapter.

[44] See section 3.7, Smith-NERA (1996), for the list of services to which either mobile or fixed prices could be applied. As a general rule mobile prices were applied below 2GHz while fixed link prices were applied above 2GHz.

[45] Smith-NERA worked with an ‘as if’ scenario so as to capture the value of the final or marginal unit of spectrum used by firms in a use sector.

Smith-NERA recommended that the price of spectrum be set equal to the estimated marginal benefit in a sector. This recommendation would result in the most efficient firms using spectrum in each sector. There would be efficiency in the assignment of spectrum within each sector. However, productive efficiency would not be satisfied across all the sectors, as this requires that the marginal benefit values to be equal across the different sectors.

In Table 3.1 a hypothetical set of estimated marginal benefits for the different frequency bands in each use sector is presented. These values assume that output and service quality in each sector is fixed and would be based on a firm of average efficiency in each use sector. In the example in Table 3.1, the price of frequency band *a* would be 100 and the price for *b* equal to 60. We can think Use 1 as being mobile and Use II being fixed links. The marginal benefit for Use III was not calculated.

Table 3.1 Estimated marginal benefits

	Frequency bands		
Uses	**a**	**b**	**c**
I	100	-	-
II	-	60	-
III	-	-	-

The Smith-NERA approach thus far is <u>partial</u> as it does not make comparisons between different categories of spectrum use, and it focuses on the potential gains stemming from changes in assignment within a sector.

The extension of the mobile and fixed link prices to other spectrum bands/uses can also be illustrated using the example given above. Assume that band *c* can be used by mobile services i.e. Use I in addition to Use III. Smith-NERA assumed that the value of band *c* to mobile services was the same as that for band *a.* The situation was as shown in Table 3.2.

Table 3.2 Spectrum prices based on the marginal benefit in Use I

	Frequency bands		
Uses	**a**	**b**	**c**
I	100	-	100
II	-	60	-
III	-	-	-

The price for frequency band *c* was set at 100, based on the estimate for Use I in frequency band a. Note that if the value of band *c* to all users for Use III was substantially below 100, then this would have the effect of clearing band *c* so that it could be used by Use I i.e. the spectrum could be reallocated. If the value of band *c* for Use III was greater than 100 then some reassignment of spectrum between Use III users is possible. The extent of any reallocation of spectrum would depend on whether and how many Use III users had a value of spectrum less than 100, and on the ability of the spectrum manager to reallocate spectrum.

Note that the pricing shown in Table 3.2 does not allow for the possibility that the allocation of band *c* spectrum to Use I may reduce the marginal value of frequency band *a* in Use I.

3.2.2 AIP in practice

The application of AIP following Smith-NERA resulted in lower prices than those proposed. The government set the prices below the marginal opportunity cost values estimated by

Smith-NERA (by at least 50%), and the estimated values were modified further to take account of other factors (usually in a downwards direction)[46].

The effect of reducing the prices on efficiency depends on how marginal opportunity costs were derived initially. For mobile and fixed link services the substantial reduction in prices may mean that some less efficient users would continue to use the spectrum, thereby reducing the extent of improvements in the efficiency of spectrum assignments (as compared with the situation in which the full Smith-NERA marginal opportunity cost estimates were used to set prices).

In the case of services/bands to which mobile or fixed link prices were applied, the reduction in prices has the effect of lowering the strength of incentives to reassign and reallocate spectrum. The impact on efficiency depends however on the marginal value of spectrum in the current use. If this value were less than the fixed or mobile price applied to the spectrum, then the Smith-NERA prices may have been set too high and the reductions made by government may have had a beneficial effect. This would not be the case if the marginal value in the current use exceeded the fixed/mobile price.

3.3 Concluding remarks

The Smith-NERA method was primarily intended to bring about improvements in the assignment of spectrum within a use sector. In practice the application of AIP was undertaken in a manner that is likely to bring about only modest improvements to assignment within bands because prices were set significantly below estimated values of marginal opportunity cost. The Smith-NERA method also addressed allocation issues for some frequency bands, although the implied prices based on marginal opportunity cost estimates may have been too high in some cases and too low in others. However, the application of AIP was based upon prices reduced substantially below the estimated marginal opportunity cost levels. The effect of reducing the estimated prices would have muted any allocation impacts.

[46] For example, in the case of mobile services values were modified based on the propagation characteristics of the spectrum, whether allocations were fragmented or not (in the case of cellular operators) and constraints on spectrum use resulting from international interference and co-ordination requirements. See “Report on Modifiers to be used in determining Administrative Pricing fee charges for mobile services”, Radiocommunications Agency 1998.

4 Refining AIP: Generalising the Opportunity Cost Approach

In this section the opportunity cost approach to spectrum pricing is extended to consider efficiency in both assignment and allocation.[47] Section 2 showed that efficiency is achieved where the marginal benefits are equal across uses (or users).[48] Spectrum pricing ought therefore to be applied in a way that encourages changes in spectrum demands so that differences in marginal benefits between uses and users diminish through time.[49]

In the previous section we showed that the original Smith-NERA recommended AIP were intended primarily to promote efficiency in assignment within a use category. In this section the Smith-NERA method is generalised in a way that allows the formulation of AIP consistent with productive efficiency across uses. To achieve efficiency in this more general setting requires a somewhat different formulation of spectrum prices than applied using the 'partial' Smith-NERA method described in the previous chapter.

Given the current assignment and allocation of spectrum is likely to be inefficient, it is unlikely that spectrum prices based on currently observed marginal opportunity costs would achieve efficiency in the medium-term. As discussed in Section 2.7, the setting of AIP should use information about the current allocation to move towards the second-best efficiency frontier. Over time this will require the application of an iterative process that gradually moves the use of spectrum in the economy towards a second-best outcome.

The marginal opportunity cost method we apply therefore considers the costs of substituting other inputs for spectrum given existing infrastructure investments and industry cost structures as a baseline. The virtue of this approach is that it is much less onerous in terms of informational requirements than estimating marginal opportunity cost at the optimum directly using a hypothetical model of costs and allocations at the optimum.[50]

4.1 Alternative uses of frequency bands

The example used in Section 3 is extended in three directions:

1 Spectrum heterogeneity across uses is introduced;

2 For a spectrum use the marginal opportunity cost of spectrum in each frequency band (whether currently used to support the use or not) is calculated; and

3 A non-spectrum input substitutable for spectrum in some uses is introduced.

[47] For the avoidance of doubt, allocation here refers to the way spectrum is allocated to uses and not to economic efficiency.

[48] This condition for efficiency holds when spectrum is homogeneous, an assumption relaxed in this section as in practice spectrum is heterogenous because radio emissions have different propagation characteristics at different frequencies (e.g. at high frequencies propagation distances are lower and absorption by buildings and other objects is higher.) Relaxing the assumption of homogeneity means that equality need not hold across all uses and users, but where substitutability is feasible in a frequency band equality of marginal benefits should hold if productive efficiency is to be achieved.

[49] Spectrum heterogeneity (and spectrum allocation constraints) will mean that efficiency is achieved in the presence of differences in marginal benefits across some users and uses.

[50] In addition, we estimate marginal opportunity cost rather than the marginal benefits to end users. At the optimum the two would be the same. However, it is in general more practical to estimate marginal opportunity costs than marginal benefits to end users since the former depends on technology and costs that are better known than end user preferences.

As in the previous chapter, it is assumed that frequency band *a* has been previously allocated entirely to Use I, frequency band *b* to Use II and frequency band *c* to Use III. The marginal benefit of the different frequency bands across the uses is shown in the Table 4.1.

Table 4.1 Marginal benefits of spectrum

	Frequency bands			Alternative non-spectrum input
Uses	**a**	**b**	**c**	
I	100	75	0	0
II	35	60	30	0
III	10	10	15	5

Spectrum heterogeneity is evident in Table 4.1. For example, frequency band *b* is worth less at the margin than frequency band *a* in Use I. Furthermore, frequency band *c* adds no value in Use I.

As discussed in the previous chapter, Smith-NERA recommended that the price of spectrum in each frequency band should be set equal to the estimated marginal benefit of the frequency band to the incumbent use. If assignment within a band were the only efficiency criterion, then this policy would achieve the objective. However, the allocation of spectrum between uses, as within uses, also matters for productive efficiency and therefore policy should be framed to account for this so as to achieve efficiency more generally.

In Section 2 it was demonstrated that efficiency (in a second-best sense) occurs where marginal benefits are brought into equality for identical spectrum.[51] In this section spectrum is assumed to be heterogeneous, and so equality of marginal benefits may not be possible because of discontinuities.

As Table 4.1 shows, frequency band *b* can be used to support Use I, and frequency band *c* can be used to support Use II. Applying the result on efficiency suggests that the marginal benefits of these frequency bands should be equalized between Use I and II and Use II and Use III respectively. For the frequency band *a*, although this can be applied in Uses II and III, the marginal benefit is at its greatest in Use I where its use is fully exhausted. Thus a capacity constraint on the availability of frequency band *a* means that equality in marginal benefits with respect to frequency band *a* cannot arise.

Marginal benefits decline as more spectrum is applied in a use. As more of frequency band *b* is allocated to Use I, the marginal benefit in Use I of using frequency band *b* would fall below 75 and the marginal benefit of using frequency band *a* would fall below 100. Similarly, where frequency band *b* is taken away from Use II, the marginal benefit to Use II of frequency band *b* increases above 60 and the marginal benefit for Use II of frequency band *c* would increase above 30. Assume that for some re-allocation of frequency band *b* between Uses I and II the marginal benefits in Use I and Use II, when employing frequency band *b,* are equalized at 70. The effect of shifting some frequency band to Use I leads to the following revised marginal benefits:

[51] Assuming continuity and homogeneity of spectrum, full information and no uncertainty.

Table 4.2 Marginal benefits of spectrum following re-allocation of frequency band *b*

Uses	Frequency bands a	b	c	Alternative non-spectrum input
I	90	70	0	0
II	38	70	32	0
III	10	10	15	5

Table 4.2 differs from Table 4.1 in that the marginal benefits of frequency bands *a* and *b* in Uses I and II have changed. This reflects the fact that Use I has more spectrum and Use II less spectrum. Due to Use II having less spectrum, the marginal benefit of frequency bands *a* and *c* in Use II have increased. The effect of re-allocating spectrum between I and II has a knock on effect on the value associated with frequency band *c* in Use II.

In Table 4.2 it can be seen that there is scope for a further efficiency gain by re-allocating some of frequency band *c* to Use II. By doing this, however, the marginal benefit of frequency band *b* in Use II will fall (as total spectrum in the use increases). Table 4.3 presents marginal benefits at a re-allocation consistent with efficiency.

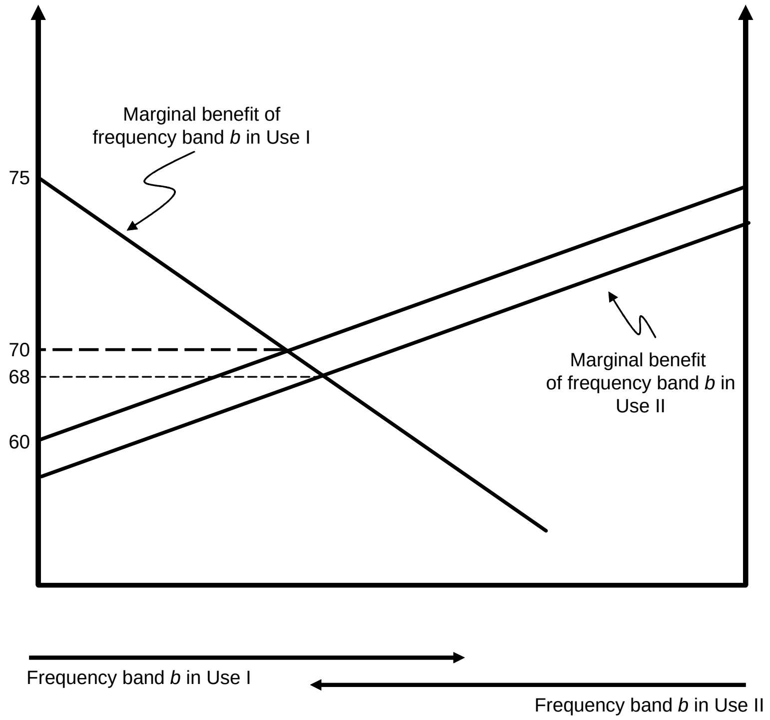
Table 4.3 Marginal benefits of spectrum following re-allocation of frequency band *c* and further re-allocation of frequency band b

Uses	Frequency bands a	b	c	Alternative non-spectrum input
I	87	68	0	0
II	36	68	25	0
III	12	12	25	4

In Table 4.3 efficiency is associated with equality in marginal benefits across users in frequency bands where substitutability of frequency bands is possible and capacity constraints are not binding: in frequency band *b* for Uses I and II and frequency band *c* for Uses II and III. See also Figure 4.1.[52]

[52] Note that the marginal benefit curve in Figure 4.1 shifts as the amount of frequency band c varies in Use II.

Figure 4.1 Marginal benefit of frequency band b in Uses I and II



Tables 4.1-4.3 suggest that an iterative approach is likely to be required in practice. This was the message delivered also in Section 2 where it was argued that information constraints would make the quantum leap to the efficient second-best optimum infeasible.

Fortunately productive efficiency can be established gradually using information about observed marginal benefits. In the next section a generalised version of Smith-NERA is presented in which it is shown that prices can be established using only observed marginal benefit (opportunity cost) values.

4.2 Generalised Smith-NERA method

To promote efficiency in both assignment and allocation, the rule for applying marginal opportunity costs to as a basis for setting AIP needs to be changed from the original Smith-NERA approach. The following describes the steps in an approach that seeks to promote re-allocation and reassignment of spectrum towards the social optimum (in a second-best sense).

An iterative approach:

1 Identify all frequency bands and associated uses (resulting in a matrix with a larger dimension than the ones shown above). In the cells enter the marginal benefits MB_{ij} appearing in use *i* (row) in frequency band *j* (column) applying the least-cost-alternative method.[53] Use the estimates of marginal opportunity cost to identify the direction of change in spectrum re-allocation. Table 4.1 informs us that at the margin frequency band *b* is more valuable to society in Use I than in Use II. Hence there ought to be a movement of spectrum from Use II to Use I. Similarly frequency band *c*

[53] The least cost method states that a user substitutes spectrum with the least cost alternative input, such that output is unchanged following a small change in spectrum.

is more valuable in Use II than in Use III, so some spectrum should move from Use III to Use II.

2 Having identified the direction of re-allocation, which will depend on spectrum substitutability and marginal benefits, identify the maximum values of the MB in each column, for each column *j* call this $MB_{ij}*$. In Table 4.1 these are 100, 75 and 30.

3 If the maximum in step 3 occurs in a use which does not currently use the frequency band (such as Use I and frequency band *b* in Table 4.1), then spectrum prices should be set to lie in the interval between $MB_{ij}*$ and the current use marginal benefit. Hence, the price of frequency band b should lie between 75 and 60.

4 Judgement is needed with respect to the actual price(s) chosen in the interval, but any information about the characteristics of the efficient allocation could guide price setting. Thus, if Table 4.3 were known, this could inform the selection of prices. Assuming Table 1 is not known, we propose that the price for frequency band *b*, for example, is set above 60 – but not significantly so.

5 If the maximum in step 3 is the value for the current use of the band then set the price at this value. This price will promote an efficient assignment of spectrum among users within this band and promote spectrum reallocation over time if the marginal opportunity cost of other spectrum that could potentially be used in the current use is lower

4.2.1 Setting the spectrum price: using judgement

Step 5 in the iterative process outlined above presents a question: If an interval is observed, what point or points in the interval should form the spectrum price(s)?

Clearly setting prices too high would lead to a fall in the use of a frequency band and new demand would likely be small. This is clearly inefficient as spectrum would not be used. It is better that spectrum is used and contributing to welfare, than not being used at all.

Setting a price close to, but not equal to the lower limit, would result in new demand for a frequency band, such as frequency band *b* in Use I, but existing demand by Use II would not fall by much. However, a price above the marginal benefit in Use II, but below Use I for frequency band *b* would lead to some spectrum being relinquished.

This approach in judging what the price for a frequency band should serve to illustrate a more general point. Erring on the side of caution and approaching the socially optimal price(s) (resulting in the equalization of marginal benefits) from below is better for welfare.[54]

4.2.2 Comments

The above analysis is intentionally simple for expositional reasons. In practice there are many different firms operating in a use within a frequency band. As already explained in Section 3, the Smith-NERA application supposes that an "average" firm is taken as a representative of all firms in a use area. In practice therefore some firms in a use will find the

[54] If a high price is set and spectrum is returned, then this could be released to higher value uses by way of auction. It is possible this route could lead to higher welfare over time than that associated with a gradual application of AIP.

AIP price too high, and other firms will find the price lying below their marginal benefit values. For AIP to work well, the selection of the representative firm has to be undertaken carefully.

In practice there may be several different sub-uses occupying a frequency band, reflecting different final markets (e.g. in a PMR band there may be taxi firms, utilities and couriers). This is likely to give rise to different estimates for the marginal benefit of spectrum in a given use. A single measure of the marginal benefit may be calculated by taking a weighted average, where the weights to use could be the amounts of frequency in the different sub-uses.

The above analysis also makes no distinction across geographic areas. However, this can be accommodated by looking at matrices for different regions. In some regions where excess demand occurs, opportunity costs will play a role in influencing prices, whereas in other regions this will not be an issue.

Time is not considered explicitly in the above example. Demands vary through time, and some future uses may not be known. Prices should therefore be periodically re-evaluated taking account of changes in demand and technology.

4.3 Concluding remarks

In this section the formulation of AIP has been analysed in the context of the allocation and assignment of spectrum. We identified the (second-best) efficient outcome and showed that the current application of Smith-NERA would not necessarily deliver productive efficiency between sectors.

An iterative procedure has been presented for identifying AIP, suggesting that current observations about opportunity costs can be used to guide a re-allocation of spectrum towards efficiency. Over time the application of such policy ought to result in the attainment of efficiency.

5 The Interaction between AIP and Spectrum Trading

5.1 Introduction

Having discussed in Sections 2-4 the formulation of spectrum prices aimed at achieving efficiency, this section addresses how AIP may work alongside spectrum trading.[55] The Independent Spectrum Review proposed that existing licences should be altered to enable spectrum trading, and in its response to the Review the Government stated that "*We will comprehensively review the current pricing methodology, re-examine licence conditions to remove any unnecessary restrictions and introduce spectrum trading*." Ofcom issued a consultation on spectrum trading in November 2003.[56]

The previous sections considered the economics of AIP on the implicit assumption that AIP is applied in the absence of spectrum trading. In this section we consider any implications of relaxing this assumption in a situation where spectrum has not been auctioned.

We note that auctions provide a mechanism for achieving an initially efficient allocation of spectrum, but do not provide a substitute for spectrum trading (or pricing) as a means of promoting an efficient allocation over time. It is therefore appropriate to consider AIP and trading as alternatives or complements, rather than to consider AIP as an alternative or complement to spectrum auctions. There is also a commitment to not impose AIP on spectrum that has been auctioned.

Three questions are considered, namely:

1 What if any implications would spectrum trading have for AIP?;

2 What if any implications would AIP have for spectrum trading?; and

3 Does AIP offer any potential advantages alongside trading?

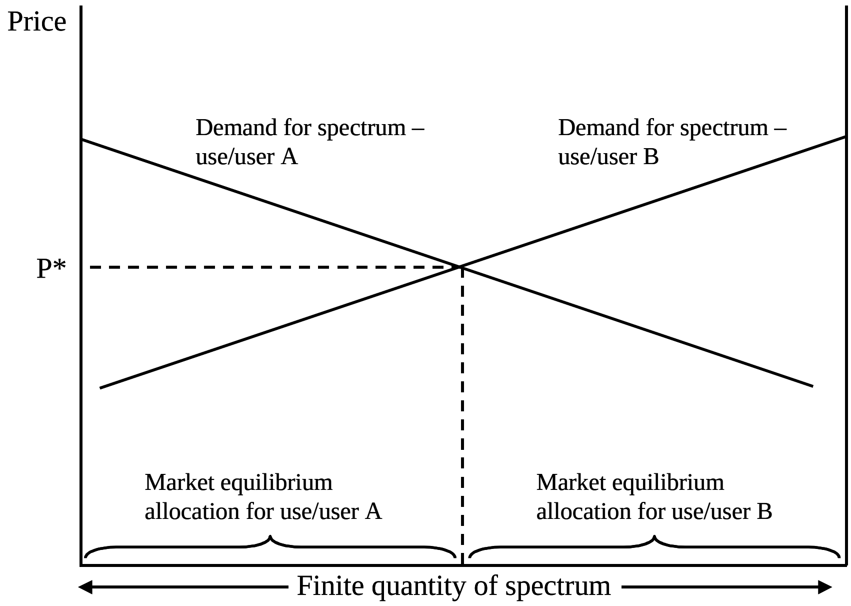
5.2 Introducing trading

Figure 5.1 illustrates a situation where there are two uses/users of spectrum (A & B). The figure allows the trading of spectrum to be considered.

[55] The economics of spectrum trading has been discussed recently by a number of economists including Gerald R. Faulhaber and David Farber (2002) "Spectrum management: property rights, markets, and the commons", Department of Economics, University of Pennsylvania; Tomasso Valletti (2001) "Spectrum Trading" *Telecommunications Policy*, vol. 25. pp. 655-670; Robert Leese, Paul Levine and Neil Rickman (2002) "The Economic Effects of Spectrum Trading", Department of Economics, University of Surrey, January; and Pablo Spiller and C. Cardilli (1999) "Towards a Property Rights approach to Communications Spectrum" *Yale Journal on Regulation*, vol. 16, pp. 53-83. The idea of trading spectrum was originally addressed by Ronald Coase (1959) "The Federal Communications Commission". *Journal of Law and Economics*, II.

[56] Spectrum Trading Consultation, Ofcom, November 2003.

Figure 5.1 Spectrum trading



In Figure 5.1 the horizontal axis is used to represent the finite quantity of spectrum available, and two demand curves are shown for competing uses/users (A&B) of available spectrum. The demand curves reflect the private values of uses/users. If trading were allowed with AIP, then trading would occur if:

1 AIP are below market clearing prices (P*);

2 the existing allocation of spectrum is inefficient;

3 transaction costs of trading (including any fees and taxes for trades) are less than the value of the potential gain from trade;

4 any information asymmetries do not prevent otherwise efficient trades

Trading would therefore tend to lead to a (privately) efficient allocation in the absence of spectrum pricing, or if the price were set below the private opportunity cost of spectrum. In terms of Figure 5.1 the competing uses/users would trade to the efficient allocation shown by the intersection of the two demand curves if their initial allocations differed from an efficient allocation. For example, if B were initially allocated all the available spectrum then A would purchase spectrum from B until the mid-point equilibrium were reached (subject to qualifications (1) to (4) above).

5.3 Asymmetry of risk in setting AIP

In Section 4 asymmetry in terms of economic costs was discussed for situations where spectrum prices were set too high versus too low. If AIP are set too high then the whole area under the demand curve for spectrum use priced off the market is lost i.e. the value of unused spectrum due to AIP is lost to society. If AIP are set too low then smaller triangles corresponding to the "deadweight loss" from any persistent inefficient use of spectrum that results are involved. Since the latter are smaller than the former (for the same magnitude of error in setting AIP), AIP should initially be set on the low side, particularly when uncertainty over the efficient level of AIP is high.

With spectrum trading the efficiency costs from setting AIP too low will generally be smaller, and may be negligible, since spectrum users can trade to a privately efficient outcome. The asymmetry in costs between setting spectrum prices too high versus too low where trading is permitted is therefore even greater, and the balance of risk therefore implies that AIP should be set even more conservatively than suggested in Section 4.

5.4 Economic rent and gains from trade

Trading does not remove any economic rent associated with scarce spectrum. Where an AIP is below P*, then a fraction of the economic rent would be removed by spectrum pricing, and the price of any spectrum trades would be corresponding lower. The transfer of "economic rent" to the government has secondary economic implications since either government expenditure will therefore be higher as a result, or taxation and borrowing will be lower. Since general taxation introduces a deadweight loss for the economy, there is a benefit from transferring economic rents to the Government, provided this does not involve a reassignment of existing property rights (a condition met for spectrum excluding spectrum sold at auction).

Spectrum pricing, which has the effect of transferring economic rent to the Government, has quite different implications for efficiency than a price (or tax) on the value of trades *per se*. Imposing a charge on the value of trades would discourage efficient trading.

5.5 Economic benefits and costs associated with trading and AIP

The benefits of efficiently set AIP and trading should in principle be the same – an efficient allocation of spectrum (leaving aside the secondary impact of changes in government revenues on economic efficiency mentioned above). This naturally raises the question of whether AIP adds anything in terms of efficiency.

In the absence of trading, and during a transition to trading, AIP clearly can improve the efficiency of spectrum use.

AIP may also have lower transaction costs, and potentially lower economic costs in terms of information asymmetry where the number of potential traders is very low (including the costs of information asymmetry). In particular, with a very small number of competing users of spectrum efficient trades will not necessarily occur.

However, if market participants are uncertain about one another's demand for spectrum it is unlikely that any central agency will have the information necessary to set spectrum prices that would yield socially optimal outcomes. Nevertheless, AIP set on a conservative basis could yield superior outcomes to thin or non-existent trading.

AIP might also promote efficiency more effectively than trading where government or other not-for-profit entities are important spectrum users, since such agencies may be more responsive to an actual cost (with AIP) than an opportunity cost (with trading), as cost minimisation is likely to be an important objective for these entities.

Finally, the observed holding of unused spectrum would not necessarily imply that spectrum pricing is superior to trading. Option values imply that the non-use of spectrum can be valuable at a given point in time (due to the option value associated with potential future uses). Holding or speculative acquisition of spectrum that is not used for a period may therefore reflect efficient behaviour. Alternatively, of course, spectrum may be held for strategic reasons, which are likely to be best addressed via general competition law or initial licensing decisions than via AIP.

5.6 Should observed traded prices inform AIP?

The analysis up to this point has left aside consideration of spectrum users' expectations regarding the introduction of spectrum pricing, and the response of spectrum prices to new information revealed by traded prices.

If AIP were linked to observed trading prices this could discourage trade (or at least discourage transparent trades). Linking AIP to observed traded prices could also discourage innovations that raise the value of existing spectrum.

To minimise disincentives to innovate one option would be to commit only to using information from trading with a lag in setting administered prices – in practice this may result in any case from the necessary administrative lag in resetting AIP. A lagged approach to new information is analogous to the approach to the response of utility regulators to new costing information, which is to adjust prices after a lag (typically 4 – 5 years in the UK). Note however that if the AIP were fixed and spectrum trading were possible, little or no inefficiency would result if the AIP were lower than the full opportunity cost, since trading would tend to ensure efficiency in any case.

5.7 Conclusions

Where spectrum trading is present alongside AIP, this will present useful information to the policy maker about marginal spectrum values. As these are required in the proposed iterative process for calculating AIP, trading can aid the application of AIP.

Spectrum prices, provided they are less than the private value of spectrum to users and potential users, would not be expected to deter trading. AIP may offer benefits over, or in addition to, trading where government or not for profit agencies hold spectrum, or where the transaction costs of trading are high and/or there are a very small number of users potentially able to trade.

6 Applying Spectrum Pricing

This section addresses three aspects of applying spectrum pricing. The first section identifies those uses to which AIP should be applied. Detailed discussion by use is given in Annex 2. The second section discusses issues in applying the methodology developed in Section 4 and indicates the approach we have used in Sections 7-10 to calculate illustrative marginal opportunity costs. The third section gives an overview of issues that arise when moving from marginal values to determining prices. These issues are considered in more detail in the service analyses given in Sections 7-10.

6.1 Uses to which AIP should be applied

AIP was introduced in 1998 and was initially applied only to mobile and fixed services, as these services were thought to experience the most acute congestion problems. Since 1998, AIP have been extended to other services and are now applied to some or all spectrum allocated to[57]:

- Defence
- Fixed links
- Maritime business radio
- Private business radio
- Programme making and special events
- Public mobile networks
- Public safety services (police, fire, ambulance services)
- Satellite uplinks (permanent and transportable earth stations and VSATs)
- Scanning telemetry (national channels only)

6.1.1 Tests for applying AIP

In deciding the frequency bands and services which should be subject to AIP the RA applies the following tests:

1. Is there excess demand for spectrum now or in the near future from existing uses of the spectrum?
2. Can the spectrum be used for another purpose[58] and , if so, is there excess demand from other uses?
3. Is it practically feasible to collect AIP fees? [59]
4. Are there any policy or political factors that prohibit the use of AIP?

If the answers to the first or second questions and the third question are positive and the answer to the final question is negative, then AIP are applied to the service/frequency band in

[57] Appendix D, Spectrum Strategy, Radiocommunications Agency 2002.

[58] Users may not be able to modify their use of spectrum in response to spectrum pricing in a variety of circumstances, such as when their use is determined by international requirements (e.g. bands used for aeronautical and maritime safety and defence bands used by NATO).

[59] This may not be possible because of problems of avoidance or illegal use.

question. AIP generally also include a geographic dimension, in that they are only applied in geographic areas where there is or may in future be excess demand for spectrum.

In applying this approach it is important to be clear about the timeframe over which congestion or excess demand for spectrum can be foreseen. Given the uncertainties in making demand forecasts for many radio-using applications this is likely to be a five year timescale, though for services not likely to experience rapid technology change or demand fluctuations a somewhat longer timeframe might be feasible (probably at most ten years).

The Independent Spectrum Review (the Review) took a similar approach in assessing which services should be subject to AIP. It recommended that AIP should be applied if the opportunity cost of spectrum is greater than zero.[60] Spectrum has a non-zero opportunity cost if one or both the first two tests have a positive answer. The practicality and policy tests are also relevant, but these did not arise in the cases examined by the Review.

The Review recommended that spectrum pricing should be extended to broadcasting services, some maritime radar services, aeronautical communications and radar services, and radio astronomy. It also suggested that opportunity cost pricing should only apply to satellite systems that share spectrum with and constrain the deployment of UK terrestrial services i.e. in shared but not exclusive satellite bands.[61]

The Review recommended the introduction of spectrum access licensing to clarify the rights and responsibilities of satellite transmissions from outside the UK to UK based receivers and that, where appropriate, opportunity cost pricing should apply to such spectrum use. This recommendation has been accepted by Government and is covered by the recognised spectrum access (RSA) provisions in the Communications Act. Although RSA would not be mandatory, only holders of an RSA would be entitled to protection from interference from other co-primary services. Since protection from interference implies a constraint on the use of spectrum by other services, RSA should therefore be subject to the same pricing principles as other forms of spectrum licensing.

6.1.2 Uses to which AIP is applied

To identify the spectrum uses that should be subject to AIP we have applied the tests listed above to each of the main spectrum uses. The analysis has been informed by the demand analyses given in the Independent Spectrum Review, the Spectrum Strategy 2002, other reviews undertaken for the RA[62] and discussions with RA staff. Detailed analysis is given in Annex 2 and a summary of our conclusions is given in Table 6.1.

We suggest that services not suitable for AIP include those for which spectrum is internationally allocated on an exclusive basis and which do not experience congestion in the current use. The main services that fall into this categorisation are NATO military bands, some aeronautical and maritime bands, amateur bands, exclusive satellite bands and bands allocated exclusively on an international basis to passive applications such as radio-astronomy or remote sensing.[63] As congestion tends to occur in specific bands and at

[60] See Recommendation 7.1, Independent Spectrum Review, March 2002.

[61] See Recommendation 8.5. op. cit.

[62] In particular: Spectrum Pricing Study: Final Report, Smith Group and NERA, 1999 and Future scenarios for the UK Info Comms Market, Ovum and Aegis, 2003.

[63] If the status of these bands was changed by the RA so they could be used by other applications, perhaps as a result of uni-lateral UK action, then AIP could become appropriate. This would need to be examined on a case by case basis.

specific geographic locations, AIP should only be applied to these bands and geographic locations.

6.1.3 Broadcasting objectives

When deciding which services are suitable for AIP it has been assumed that the objective is to promote economic efficiency. However, the Government's response to the Independent Spectrum Review stated that AIP applied to analogue television should promote digital switchover and, in the case of digital terrestrial TV, AIP should also promote more efficient use of the spectrum. A difficulty with the objective of promoting switchover is that, unlike the efficiency objective, it does not provide a unique price. Many levels of price could encourage broadcasters to make expenditures aimed at speeding up migration from analogue to digital TV. The price needs to be large enough to mean the expected gain from increasing the chance of switchover/reducing the time to switchover (i.e. lower spectrum fee and other costs saved) exceeds the costs of promoting switchover (e.g. infrastructure costs of increased coverage for digital services and costs of market stimulation). Furthermore, the switchover objective and the efficiency objective may not be identical. Our approach has been to assume efficiency is to be promoted and then to assess whether the resulting prices are likely to provide an incentive to promote switchover.

There is also a specific requirement for this study to make recommendations on the relevant objectives for sound broadcasting and the extent to which AIP would be appropriate given the constraints imposed by the broadcasting regulatory framework. We have had discussions on this issue with the Radio Authority and broadcasting division staff in the RA. Possible objectives for pricing sound broadcasting are to promote economic efficiency and/or promote the transition to digital audio broadcasts (DAB). Unlike the situation with TV, there is no Government plan or proposal for a plan for switchover. For this reason it would not seem appropriate (at this time) to adopt promotion of switchover as an objective. It is therefore recommended that the objective for AIP for sound broadcasting should be to promote economic efficiency, subject to the constraints of broadcasting policy. While these constraints limit the benefits from applying AIP to analogue radio spectrum, the application of AIP could provide users with incentives to seek a relaxation of the constraints. In the case of digital spectrum, users are likely to have more flexibility in which case AIP should be applied.

Table 6.1 Summary of Conclusions on Applying Administrative Incentive Pricing

Service	Excess demand – existing use	Demand from alternative uses	Can the spectrum be used for another purpose?	Policy or practical impediments	Suitable for pricing
Aeronautical communication	Yes in 118-137 MHz band	Generally no	Some limited scope for other aeronautical services (radiolocation or navigation)	International bands	Yes in 118-137 MHz band
Aeronautical radar	Probably not currently but may be in future	In some bands (e.g. UHF Ch 36)	Yes (UHF Ch 36 for broadcasting and other spectrum for PMSE / ENG)	International bands in most cases (does not apply to UHF Ch 36)	Yes in UK-only allocations. Differential pricing to reflect out of band interference.
Broadcasting – TV	Yes	Yes (e.g. mobile or broadcast data applications and PMSE)	Yes in longer term – analogue TV. Yes- digital TV	Broadcasting policy; European TV plan	Yes, to promote switchover after 2006 and efficient spectrum use after 2010
Broadcasting – sound	Yes – analogue And digital in some locations	Limited - analogue. Potential PMR/PAMR demand (Band III) or S-DAB (L-band)– digital	Yes, limited in practice esp. in analogue bands, due to international allocations	Licence conditions for commercial operators; policy for the BBC	Yes, once licensees have possibility of changing spectrum use
Defence	Probably not	In some bands (some already shared geographically)	Yes, except most NATO allocations	NATO allocations	Yes, except NATO bands
Fixed links	Yes (in some bands & locations)	No	Yes	No	Yes
FWA	Not in near term	Yes (mainly fixed links)	Yes	Yes, Broadband Britain agenda	Yes
Scanning Telemetry	No	Yes (PMR / PAMR)	Yes	No	Yes
Maritime communication	**Yes, in certain bands and areas (e.g. VHF on south coast)**	**Yes in some bands – PMR in business maritime bands**	**Yes, except for internationally agreed channels**	**Certain channels allocated internationally for safety**	**Yes, for maritime business radio**

Service	Excess demand – existing use	Demand from alternative uses	Can the spectrum be used for another purpose?	Policy or practical impediments	Suitable for pricing
Maritime radar	Probably not	Unlikely – international allocations or unsuitable for other uses	Limited - international bands	International bands	No except for differential pricing to reflect out of band interference
PMSE	Yes	Yes	Yes	No	Yes
PMR	Yes (in some bands and areas)	Yes in some bands (e.g. PAMR)	Yes (for some bands)	No	Yes
Public Safety	Not currently (TETRA now available), potentially in longer term	Yes	Yes (e.g. migration to Airwave TETRA network)	Certain users reluctant to migrate	Yes (except possibly Airwave network – sharing NATO spectrum)
Public Mobile Networks	Yes for cellular & PAMR, CBS in certain bands / areas. No for paging, mobile data.	Yes (e.g. other mobile uses)	Yes, in most bands	International obligations (e.g. GSM Directive)	Yes
Satellite	No, except possibly L Band mobile services	Yes (in bands shared with fixed links)	Yes, except in internationally designated exclusive bands	RSA in some cases. “Free rider” issue.	Yes, shared bands only (requires RSA for downlinks)
Science services	No	Yes in non-exclusive bands (e.g. TV channel 38)	Yes, except in internationally designated exclusive bands	Needs RSA	Yes, with RSA (except internationally allocated exclusive bands)

6.2 Issues in Applying the AIP methodology

The steps in calculating AIP using the methodology developed in Section 4 are as follows:

1. For a given frequency band identify the current and other potential uses of the band.
2. Calculate the marginal private value (i.e. opportunity cost) of spectrum for the current use of the band and other uses until a use is found which has a higher marginal private value than the current use.
3. If there is a use with a marginal private value higher than the current use of the band then set the AIP between the two values, but towards the bottom end of the range of values.
4. If there is no use with an opportunity cost higher than the current use of the band then set the AIP at the value for the current use.

This approach assumes that it is possible to reallocate spectrum administratively from the current use of the band in question to other potential uses. The feasibility of achieving this over the timescale for which prices are set, say five years, needs to be considered. In bands that are shared between different uses reallocation will relatively be straightforward but it may not be the case for other bands. If it is not likely to be feasible to reallocate the spectrum in these timescales,[64] then only the marginal value for the current use should be used to determine AIP.

As explained in Section 2 the (second best) welfare optimum is achieved when spectrum prices are set consistent with productive efficiency. The appropriate way of dealing with the effects of market failure is through policy instruments applied to final service markets. (e.g. price regulation in telecom markets, universal service obligations and content regulation of broadcasters or direct grants or subsidies to FWA for rural areas) and not through changes to the pricing of an input such as spectrum.

6.2.1 Calculating marginal opportunity costs

Marginal opportunity costs are calculated using the approach developed by Smith-NERA, namely the marginal opportunity cost of spectrum is the additional cost (or cost saving) to an average or reasonably efficient user as a result of being denied access to a small amount of spectrum (or being given access to an additional small amount of spectrum). The additional cost (cost saving) depends on the application and is calculated as the estimated minimum cost of the alternative actions facing the user. These alternatives may include

- investing in more/less network infrastructure to achieve the same quantity and quality of output with less/more spectrum;
- adopting narrower bandwidth equipment;
- switching to an alternative band;
- switching to an alternative service (e.g. a public service rather than private communications) or technology (e.g. fibre or leased line rather than fixed radio link).

[64] This may be because there is no equipment available for the new use in the given frequency band. Current administrative processes for reallocating spectrum are slow (taking at least seven years), however, this may change when these processes are replaced by market mechanisms such as trading and the auctioning of overlay licences.

This approach overstates the marginal opportunity cost of spectrum for reductions in spectrum and understates the marginal opportunity cost for increases in spectrum.[65] An average of the values obtained from an increase and a decrease in spectrum gives a reasonable approximation to the value. In practice, it has not always been feasible to estimate values for increases and decreases in spectrum and so there may be some small bias in our results.

6.2.2 Assumptions

To derive marginal opportunity costs we have made assumptions concerning:

- The change in the amount of spectrum to which a user has access.
- The nature of an average (or reasonably efficient) user, in terms of transmission network topology and characteristics of equipment used (e.g. age, bandwidth, power) given their radio communication demands (e.g. local or national, traffic levels, service quality requirements).
- The discount rate and discounting period used to convert one-off costs into annualised values.
- Equipment maintenance costs. These are assumed to be 12% of capital costs.
- The maturity of the existing networks, e.g. in the case of GSM spectrum it is assumed that networks are fully developed in coverage terms and that any marginal change in the spectrum assigned would only affect the capacity of the network in areas of peak demand by increasing or decreasing the level of infrastructure required to serve these areas.

6.2.2.1 Change in spectrum

The marginal opportunity cost of spectrum is defined as the value of spectrum resulting from a small change in spectrum used. The marginal increase or decrease in spectrum chosen should reflect the minimum amount that is likely to be of practical benefit to the user, for example in the case of a cellular network this should take account of typical cellular re-use patterns.

This amount differs by service. For example, for PMR services it is a 2 x 12.5 kHz channel,[66] whereas for aeronautical communications it is 25 kHz and for cellular or PAMR services it is the number of channels required to populate a single cell "cluster", taking account of typical planning parameters.

6.2.2.2 An average user

Our approach to defining a reasonably efficient user for the purposes of determining marginal values is based on information provided by the RA concerning the range of different types of users, information gathered from secondary sources and our industry and engineering knowledge.

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[65] The difference arises because faced with a change in the quantity of spectrum, a profit maximising firm would change its output. In the least-cost-alternative approach where we apply the Pareto criterion, we assume that output is unchanged. While unrealistic as an assumption, it enables a proper test for efficiency.

[66] Many of the services addressed by this report use frequency division duplexing whereby each radio channel comprises a pair of frequencies to facilitate two-way communication, hence the minimum amount of spectrum is defined as 2 x N kHz.

In some cases (notably fixed links), the relation between costs and bandwidth is non-linear as a high proportion of costs are fixed (i.e. are independent of bandwidth). Consequently there is a wide variation in the marginal value determined for individual link types. However, since the regulator does not specify particular frequency bands for particular link types, it is necessary to define a single marginal value for these bands. To do so, we have identified the marginal values for each main link type and from these determined a weighted average value reflecting the total amount of spectrum utilised by each link type. Inevitably some degree of judgement is used in deriving the assumed user profiles.

6.2.2.3 Discounting

One-off costs need to be converted to annualised values because there are capital and annual cost differences between spectrum use options and the marginal value of spectrum needs to be an annual value as it is used to set a price that is charged on an annual basis (unlike auction payments which are generally one-off lump sum payments). We have assumed the following real discount rates and discount periods for the various services considered:

- Fixed links, satellite and broadcasting: a 10% real discount rate over 15 years;
- Mobile and FWA: a 10% real discount rate over 10 years;
- Aeronautical: a 7.75% discount rate over 15 years.

The values for telecommunications and broadcast services are consistent with those used in the original Smith-NERA study, the cost of capital values used by telecom and broadcasting regulators[67] and asset life assumptions used in mobile service modelling undertaken for Oftel.[68] Those for aeronautical reflect values used by the Civil Aviation Authority.[69]

6.3 Determining AIP

Prices of spectrum should be a function of the spectrum use denied to other users and this typically depends on the bandwidth used and the geographic area over which use is denied i.e. the area sterilised by the service. The concept of area sterilised is appropriate for services such as mobile and broadcasting but works less well for fixed links where congestion at specific nodal sites is often the main constraint on spectrum use. In Section 7 we discuss how this could be taken into account when setting fees for fixed links.

Marginal values obtained for a local frequency assignment, such as PMR or CBS, can be converted to a national value by multiplying the local value by the likely amount of frequency reuse. This approach implicitly assumes that spectrum use is congested all over the UK. It will be important to test whether this assumption holds or not when converting marginal values into AIP. If the assumption does not hold and there is excess demand for spectrum in some but not all locations, then the national value should be calculated as relevant multiples of the congested and non-congested values where the multiples depend on the extent of congestion.

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[67] A 10% real discount rate is used by the Independent Television Commission in "Channel 5, Licence Renewal Methodology and Procedure", ITC, April 2003. Oftel uses a nominal cost of capital of 13.5% for BT and the Competition Commission used a nominal value of 14% for operators in the cellular mobile industry.

[68] The LRIC model developed by Analysys for Oftel.

[69] "Economic Regulation of BAA London Airports, 2003-2008, CAA Decision, February 2003.

For some services (e.g. PMR or FWA) it may be appropriate to apply weighting metrics such as population or the number of businesses within the area where spectrum is consumed as a proxy for the degree of congestion. In other cases (e.g. fixed links), congestion may be measured in terms of the actual level of use at specific locations, as determined from the RA's licensing database.

6.4 Summary

In principle bands used by most services, with the exception of those that are internationally allocated on an exclusive basis and do not experience congestion, should be subject to AIP. The specific bands and geographic locations at which AIP should be applied depend on the extent of use and, in particular, whether congestion is experienced. This needs to be considered on a case by case basis. We have undertaken a high level analysis of the situation by service in Sections 7-10 and Annex 2.

To apply the methodology developed in Section 4 judgements are required concerning the potential alternative uses of spectrum in the bands under consideration. These judgements should be based on the uses that could realistically use the band over the period between pricing reviews. Marginal values or opportunity costs are calculated using the least cost alternative approach developed by Smith-NERA (1996). To derive AIP from marginal values the spectrum use denied needs to be estimated based on the bandwidth and geographic area sterilised by the application under consideration.

7 Fixed Services

This section discusses the marginal opportunity costs we have obtained for fixed links, FWA, fixed satellite services and scanning telemetry and compares the implied values with those recommended by Smith-NERA and the current level of fees paid. Where relevant we also comment on the formulae currently used or proposed by the RA to convert marginal values into fees.

7.1 Fixed Links

7.1.1 Marginal value

Estimates of the marginal value of spectrum for fixed links are derived in Annex 3. We obtained a weighted average value of £132 per 2x1 MHz link, which is substantially lower than the Smith-NERA value of £380 per 2x1 MHz link. A key difference from the Smith-NERA methodology is that we have adopted use of a more efficient technology as the lowest cost alternative rather than moving to a higher frequency band.[70] This is partly because the availability of more efficient equipment has improved considerably since 1996 and prices have fallen, whilst the cost of site acquisition and rental has tended to rise, reflecting the greater demand for space on existing sites for other radio applications.

We have determined the marginal value on a per-link basis, rather than as a standard tariff unit (STU). This is because the RA now licenses all links on a per-link basis (whereas previously certain operators had national "block" allocations) and also because of the difficulty of defining with any degree of accuracy the area effectively sterilised by individual fixed links.[71]

This does pose a problem in terms of comparing the value in shared bands (e.g. fixed / satellite) but this can be overcome by estimating the maximum number of links that might be accommodated in a given (congested) geographic area, which would enable an equivalent STU to be derived. We suggest that an appropriate figure for link density could be derived from the RA's fixed link database. In the meantime, for illustrative purposes we have estimated a value for the area sterilised by a typical fixed link in a frequency band that can be used also for FWA and fixed satellite services (section 7.5).

7.1.2 Determining AIP

Having determined a marginal value for fixed link spectrum on a per-link, per MHz basis, it is necessary to translate this into prices that can be applied to specific links. In consultation with

[70] In determining values for specific bands, Smith / NERA assumed that operators of links in bands below 13 GHz would migrate to bands in the range 13 – 22 GHz, while existing operators with links in the 13 – 22 GHz bands would migrate to 38 GHz. The annualised cost of migrating from 13 – 22 GHz to 38 GHz was determined to be £17,000 for a typical link of 2 x 14 MHz, whereas the cost of migrating from below 13 GHz to 13 – 22 GHz was found to be £20,000. The marginal value of spectrum in the 13 – 22 GHz bands was therefore set at £17,000 per link, corresponding to the cost of migrating from these bands, on the basis that the higher (38 GHz) band would be uncongested and therefore have zero marginal value. The marginal value of spectrum in the bands below 13 GHz needed to set at a level which reflected both the cost of migration and the fact that the higher band itself had a positive marginal value of £17,000 per link. Since two links would be required in the higher frequency band, the marginal value of the lower band would need to include a sum equal to twice per-link value of the higher band, in addition to the migration cost. Hence the marginal value for the bands below 13 GHz was set at £54,000 per link.

[71] The area sterilised by a fixed link depends on many factors, such as aerial height, terrain, modulation scheme and availability.

industry, the Agency has recently proposed the following algorithm for determination of individual link fees:

Equation 7.1

Licence Fee	=	**Reference Fee x Path Length$_{mod}$ x Band Width$_{mod}$ x Congestion$_{mod}$ x Band$_{mod}$ x Availability$_{mod}$ x Technology Usage$_{mod}$ x Weighted Average Antenna$_{mod}$**

Where:

- Reference fee = per-link marginal value, normalised to standard reference link bandwidth (28 MHz in most bands)
- Path length modifier applies a premium where the link length is less than the minimum stipulated by the Agency for the band
- Bandwidth modifier is a multiplier to reflect the actual licensed bandwidth (MHz)
- Congestion modifier is intended to define whether sites or geographic areas are congested or not
- Band modifier is intended to take account of the characteristics of different frequency bands
- Availability takes account of the greater denial of spectrum resulting from higher availability levels
- Technology usage modifier applies a lower fee to technologies that are considered more spectrally efficient
- Weighted average antenna modifier applies a lower fee to antenna systems that are considered more spectrally efficient

We have reviewed the Agency's proposed algorithm and are in agreement with a number of the elements proposed. In particular, the inclusion of availability is welcomed since it is clear that higher availability links require both higher emission levels and greater protection from interference, resulting in considerably greater denial of spectrum to other users. We recommend that the regulator carries out its own analysis of link capacity in specific bands and areas to ascertain the validity of the proposed pricing differentials for links of differing availability.

We also support the application of a path length modifier (i.e. premium to discourage the deployment of links that are shorter than the RA's stipulated minimum) and understand that the purpose of this modifier is to achieve appropriate link lengths through pricing rather the current administrative rule (the link length policy). The inclusion of frequency band and antenna technology modifiers to reflect the differing frequency re-use capability of frequency bands and antenna classes is also sensible, and as with availability we suggest the Agency carries out its own analysis of link capacities in various bands and with different antenna classes to verify the differentials proposed.

The inclusion of a "technology modifier" appears to be a legacy from the RA's current application of spectrum pricing to fixed links. Under the current approach, spectrum fees for links using similar technology are not directly proportional to bandwidth and the differential between links of different bandwidths is substantially less than would be the case if they were proportional. For example, the difference between a 28 MHz and 14 MHz link using the least efficient technology is not 2:1 as the bandwidth differential would imply, but only 1.54:1. The

RA has applied a technology modifier which has the effect of restoring the direct proportionality between bandwidth and licence fee when a reduction in bandwidth is accompanied by a switch to a more efficient technology, so the ratio between the fee for a 28 MHz link using the least efficient technology and a 14 MHz link using the most efficient technology is 2:1. We suggest that a technology modifier is inappropriate if the bandwidth modifier is directly proportional to bandwidth, as is the case in the RA's currently proposed algorithm.

The deployment of more bandwidth-efficient technology in a fixed link results in a greater area sterilised and reduces by around 50% the overall saving in spectrum utilisation that would be implied by consideration of the bandwidth efficiency alone. However the capacity at individual link nodes is more directly related to the bandwidth efficiency and since congestion in fixed link bands tends to be site-specific rather than area-specific we do not consider it necessary to factor this increase in sterilised area into individual link fees. We have however taken it into account in our estimate of the marginal value of fixed link spectrum, due to its impact on the overall capacity of the spectrum.

The application of a congestion modifier presumes that there is a direct relation between licence fees in congested and uncongested areas, whereas this should not be the case if uncongested fees are set, as we recommend in Section 11, on a cost recovery basis. If AIP are only applied in congested areas, the inclusion of a congestion modifier in the algorithm becomes redundant.

To summarise, we recommend that the determination of the licence fee for fixed links in a congested area should be based on the following algorithm:

Equation 7.2 Recommended algorithm for calculating fixed link fees

Fee = Marginal Value (£ per 2x1 MHz) x bandwidth modifier* x path length modifier* x frequency band modifier x antenna technology modifier* x availability modifier*.

* * Radiocommunications Agency. January 2003. "Fixed links spectrum pricing proposal". v1.1

Equation 7.2 compares fees under the current and proposed regimes for various types of link operating in congested areas / frequency bands. It is assumed that the link length exceeds the minimum for the band and that all modifiers in the above algorithm are unity except for the bandwidth in MHz and the frequency band modifier, which is unity for 13 GHz, 1.7 for 7.5 GHz and 2.3 for 4 GHz, as currently proposed by the Agency.

Table 7.1

Link type (band, bandwidth)	Fee based on Smith / NERA STU[72]	Current fee[73]	New fee
7.5 GHz, 14 MHz	£9,044	£1,230	£3,142
7.5 GHz, 28 MHz	£18,088	£1,900	£6,283
7.5 GHz, 56 MHz	£36,716	£2,450	£12,566
13 GHz, 7 MHz	£2,660	£615	£924
4 GHz, 30 MHz	£26,220	£1,225	£9,108

It can be seen that the new fees are much lower than those that would be obtained by applying the original Smith-NERA STU value to the above algorithm, but are substantially higher than those currently applied. This partly reflects the fact that the current fees are not based on the Smith-NERA recommendations and also that we have assumed a 50% reduction in bandwidth by adopting a more efficient technology would result in only a 25% reduction in spectrum utilisation when re-use is taken into account.

The effect of the higher fees could be mitigated by changing the nature of the frequency band modifier. The frequency band modifier is currently set at unity for the 13 – 18 GHz bands, which in practice are the highest frequency bands currently considered by the RA to be congested. If the value was set at unity for the 7.5 GHz band, which lies in the mid-range of the frequency bands currently congested, this would reduce the proposed fee levels by 42%, as shown in Table 7.2. The choice of the 7.5 GHz band as the "reference band" is based on the fact that this is the median of the five currently congested bands (i.e. 4, 6, 7.5, 13 and 14 GHz) and because lower bands have less re-use potential (due to lower free space path loss) and higher bands have better re-use potential. If in future higher frequency bands become congested it would be necessary to revise the reference band accordingly. This approach has the advantages of simplicity and transparency and also reflects the link between frequency and re-use without the need for complex modelling of re-use capability.

Table 7.2

Link type	Current fee	New fee with frequency band modifier referenced to 7.5 GHz
7.5 GHz, 14 MHz	£1,230	£1,851
7.5 GHz, 28 MHz	£1,900	£3,702
7.5 GHz, 56 MHz	£2,450	£7,404
13 GHz, 7 MHz	£615	£543
4 GHz, 30 MHz	£1,225	£4,469

[72] Using the algorithm in Section 7.1.2 with a marginal value of £380 per 2 x 1 MHz link.

[73] Note that the reference fee or marginal value in the fixed link formula that currently applies was based on the fee that applied in 1997 and not the Smith/NERA recommendations. See para A.21 Implementing Spectrum pricing, A Consultation Document on Administrative Pricing, RA, May 1997

7.1.3 Congestion

Frequency bands up to and including 14 GHz are currently considered to be congested in certain geographic areas, defined by 10 km or 25 km grid squares depending upon the band. Links within these areas have prices set in accordance with the STU and modifiers, whereas links outside these areas have lower prices that are set typically at levels up to around half the level of the congested fees.

As discussed in Annex 2, the 23 GHz band also seems likely to become congested in some locations in future and we recommend that the regulator considers extending the scope of pricing to this band. The RA has recently proposed that congestion should be defined on the basis of specific locations rather than grid squares, however this has raised concerns that it could serve to discourage site sharing which may run counter to broader planning criteria. A reasonable compromise may be to define a nominal radius around an existing congested site, corresponding to the typical distance between existing sites. Appropriate distances could be determined by analysis of the Agency's link database, however we suggest that initially distances of 3 km in urban areas, 5 km in suburban areas and 10 km in rural areas may be suitable.

7.2 Fixed Wireless Access

7.2.1 Marginal value

Determining a marginal value for FWA spectrum is complicated by the immature nature of the market and the fact that the least-cost alternative will vary depending on the nature of the service being provided. For example, spectrum in the 3.5 GHz or 10 GHz band is most likely to be suited to deliver of services akin to digital subscriber line (DSL) or cable modem offerings, i.e. contended services with maximum data rates of up to 1 Mbit/s, whereas the 28 GHz band is more likely to be used to deliver higher speed, committed data rate services that would compete with leased line offerings. Comparing the cost of these alternatives is difficult as the costs of both providing FWA services and accessing the alternatives are continually evolving (e.g. the cost of wholesale access to BT's ADSL network has fallen by around 40% over the last two years).

We have nevertheless derived illustrative marginal values for FWA in Annex 4, based on the cost differential with alternative wire line services. This suggests a value of £2,548 per 2 x 1 MHz per base station for an FWA system providing consumer ADSL-type services at a 40:1 contention ratio in the bands up to 10 GHz and comprising one sector of a four-sector base station with an aggregate bit rate of 2 Mbit/s. The value reduces to £581 per 2 x 1 MHz if the contention ratio is assumed to be 20:1, but rises to £33,296 if the alternative platform is considered to be business SDSL with a 10:1 contention ratio (based on current pricing of the alternative platform). The corresponding value for a 28 GHz system lies between these values at £4,800 per 2 x 1 MHz per base station. The lower value compared to the 3.5 GHz business offering is in part due to the higher cost of equipment in the 28 GHz band. Note that all of these figures are highly sensitive to the cost assumptions made in the calculations (both for the FWA equipment and the wire-line alternative) and given the current uncertain nature of the FWA market are inevitably somewhat speculative.

While it might be argued that FWA is intended to supply services in areas not reached by DSL, this would effectively limit FWA use to rural areas and small towns where spectrum pricing is unlikely to apply.[74] FWA services are provided in urban areas and the marginal values we have estimated are relevant in these circumstances.

7.2.2 Determining AIP

FWA competes for spectrum with fixed links and, following the recent removal of restrictions relating to the purpose of use, FWA systems may be used for the same applications as fixed links. Under the proposed pricing methodology, AIP for these bands should lie between the value for the current use and the use with the next highest marginal value. This would suggest setting AIP for FWA between the marginal values for FWA and fixed links. However, the level chosen needs to take account of the fact that FWA spectrum may now be used for fixed links infrastructure. If fees for FWA spectrum were substantially below those for fixed links (on an equivalent MHz/km^2 basis) then this would distort users' choice of spectrum. This suggests that fees for FWA should be set on the same basis as fixed links fees.

7.2.3 Congestion

Spectrum at 3.5 GHz and 28 GHz that was assigned by auction for FWA will not be subject to AIP. Spectrum that could in principle be priced comprises the existing 4 GHz and 10 GHz bands and the remainder of the 28 GHz spectrum that was not sold at auction. In practice whether AIP is applied depends on the degree of congestion in these bands and whether the spectrum is auctioned in the future.

The 10 GHz fixed link band is currently classed as congested at some locations, although we understand this is not borne out by current levels of use. The conclusion that the 28 GHz band is not congested is based on the premise that there has been no demand for 28 GHz licences that are currently offered on a first come first served basis but subject to the reserve prices set for the auction in 2000.

It is interesting to compare the marginal values that have been determined with the amounts bid in recent auctions. Assuming a regional system with 10 base stations and 2 x 112 MHz in total in the 28 GHz band, implies a total marginal value of (112 x 4,800 x 10) = £5.38m. The highest amount paid in the 2000 auction for 28 GHz licences was £7.37m, equivalent to an annual payment of £1.09m, suggesting that in this case the market value of the spectrum is lower than the least-cost alternative would suggest. In the case of the 3.5 GHz band, a 10-base station system with 2 x 20 MHz would have a marginal value of (2,548 x 20 x 10) = £509,600, whereas the maximum auction bid was £1.92m, equivalent to an annual payment £284,000 and suggesting again that the market value is less than the marginal value we have determined.

In view of this uncertainty, we suggest that AIP should only be applied to FWA in the areas that are defined as congested for fixed links (or any other shared services).

7.3 Satellite Services

In Section 6 we recommended that AIP should only be applied to satellite services using shared bands. Broadcasting and mobile satellite services generally operate in exclusive bands and so are not considered as candidates for AIP.[75] The focus is therefore on the

[74] 71% of households are covered by ADSL enabled exchanges and 95% of those households were close enough to the exchange to receive a DSL service. DSL Fact Sheet, Oftel, September 2003.

[75] Note the spectrum used by BSkyB is in a fixed services band and is mostly shared with fixed links.

marginal value of spectrum for satellite services operating in bands shared with the fixed service.

7.3.1 Current fees

The current approach to setting prices for satellite networks and permanent earth stations is set out in Appendix 4 of Spectrum Pricing: Third Stage Update and Consultation, December 2000. The licence fee is defined as the vector sum of the transmit and receive elements with the receive element set equal to zero at present. The rationale for adopting the vector sum is not clear to us and is not explained by the RA in its consultation documents.

The fee for the transmit element is a function of the bandwidth to which access is authorised, the peak transmit power, a constant factor and a number of modifiers.[76] The modifiers are intended to capture aspects of satellite operation that might affect the spectrum access denied to other users and include elevation angle, height, location, screening and multiple satellite clearances at a single earth station. At present these modifiers are all set at one and so have no impact on the level of fees. A further modifier is applied depending on whether the band in question is shared with fixed links or not. The modifier has a value of one in shared bands and 0.5 in exclusive satellite bands. The basis for the latter modifier is not clear since as we have already noted spectrum congestion does not arise in exclusive bands.

The constant factor in the formula is derived from the calculation of a reference fee for fixed satellite service (FSS) access to spectrum. The reference fee for access to 575 MHz at a transmit power of 1000W is calculated from the fixed link price in a congested area for a unidirectional 28 MHz bandwidth STM-1 multiplied by the ratio of bandwidth available for a permanent earth station to that for the fixed link. The assumption seems to be that area over which use is denied is similar for the two systems and hence the only scaling that is done is by bandwidth.

7.3.2 Marginal value

In Annex 5 we derive a marginal value of spectrum for satellite services based on the trade-off between power and bandwidth that might be made by a satellite system designer. This gives a value of £140,000 p.a. for the 5 MHz bandwidth change in the example, or £28,000/MHz p.a. equivalently. Such encouragement to use smaller bandwidths is unlikely to be possible in practice because decisions about satellite link design are based on satellite power rather than bandwidth considerations unless fees of the order of £28,000/MHz are charged. However, it should be possible to encourage lower transmitter powers in earth stations because of the trade-off between dish size and transmitter power in order to achieve a required effective isotropically radiated power (EIRP). This aspect relates more to the opportunity cost with respect to alternative terrestrial services rather than the least cost alternative addressed above.

FSS fees are currently set based to some extent upon the methodology developed by Smith-NERA for fixed links and satellite services, in which the fee reflects the bandwidth and geographic area that is denied to other users. The Smith-NERA calculation is based on the same STU (expressed in £ / MHz / km^2) as that used for terrestrial fixed links,[77] and is thus

[76] Formulae for calculating fees are given in Schedule 8, Statutory Instrument 1700, 2002.

[77] While Smith-NERA make a direct link with the STU, current pricing relates the fixed satellite service reference fee to the fee for a particular fixed link. Although current pricing takes account of the effect of earth station denial area

only really valid where spectrum is shared between terrestrial fixed and fixed satellite services.[78] Whilst the methodology developed by Smith-NERA is sound in principle, the assumption that the EIRP radiated horizontally by a satellite earth station is about the same as that radiated on boresight by a typical fixed link seems odd. Since the earth station is effectively an omni-directional radiator in the horizontal plane, this assumption results in a much greater area sterilised by an earth station than by a fixed link – typically around a 200-fold increase. The key issue is whether one should be comparing denial areas on the basis of the same transmitter powers (as per the Smith-NERA assumption) or on typical transmitter powers used by the two services.

We have re-worked the calculations based on a fixed link EIRP of 46 dBW (transmitter power of 2 dBW) and a FSS earth station EIRP in the horizontal plane of 15 dBW over a 90 deg segment and 10 dBW over the rest (transmitter power of 20 dBW). This results in a denial area for the earth station of between 2.8 and 6.25 times that of a typical fixed link, depending on whether the effect of the fixed link on the region beyond the remote end of the link ("overshoot") is considered.

On the basis of current pricing regime, which is not based on a denial area relationship, a unidirectional 30 MHz / 140 Mbit/s fixed link in a congested area attracts a fee of £920 per annum and an earth station using 30 MHz of bandwidth and employing a transmitter power of 100 Watts in a shared frequency band attracts a fee of £1140 per annum. While the current fees are comparable for the examples chosen, the denial area comparison suggests that the earth station fee should be in the range £2576 to £5750 per annum (2.25 to 5 times greater than at present).

7.3.3 Congestion

Administered incentive pricing is applied to satellite services in all frequency bands between 5.8 and 30 GHz, including bands shared with fixed links above 15GHz where the fixed links fees are set assuming the band is uncongested. As AIP is applied to satellite services because of the use denied to fixed link services, it seems appropriate that AIP for satellite services is only applied in those bands where fixed links experience congestion i.e. 23 GHz and below. There would appear to be an inconsistency here. This could be addressed by looking at the fixed service as a whole and then designating bands as congested or uncongested.

7.4 Scanning Telemetry

This fixed service uses an exclusive block of 2x1 MHz of spectrum in the 450-470 MHz band, which is currently in heavy demand from PMR services and could in future face demand from PAMR or cellular services. Pricing is justified on this basis. Since the technology used is very similar to PMR, the costs and hence the value of the spectrum to the user are also likely to be similar. It is therefore suggested that the AIP derived for PMR are applied to this service.

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through the transmitter power parameter, it has lost the direct relationship between the denial area of a fixed link terminal versus that of a fixed satellite service terminal.

[78] This is a reasonable assumption to make, since where spectrum is allocated exclusively to the fixed satellite service spectrum capacity is more a function of orbital re-use than spectrum availability and demand is effectively regulated by the charges applied by satellite platform operators for access to transponders.

7.5 Summary

It is possible to compare the marginal value of fixed services spectrum if certain assumptions are made about the geographic characteristics of particular services (i.e. area sterilised). The 4 GHz band is currently used by fixed links, FWA and satellite services and serves as a useful example for a comparison to be made between the value of spectrum for these three services, by comparing the marginal values on a per MHz, per km^2 basis.

We have estimated the area sterilised by a typical 4 GHz fixed link, assuming a 44 dBi gain antenna to be 180 km^2 and a 40 km hop length with a 40 km "overshoot" (i.e. the beam continues to pose an interference risk at a distance 40 km beyond the remote end of the link). The area sterilised by a 4 GHz FWA sector is assumed to a 90 degree arc of radius 30 km, i.e. 707 km^2, whereas we estimate that the area sterilised by a hypothetical satellite earth station at C-band (4/6 GHz) would be of the order of 500 km^2.

Taking these sterilisation areas into account, the marginal values for the three services are:

Table 7.3

	Fixed Links	FWA	Satellite
Marginal value per 2 x 1 MHz	£132 per link	£581 - £33,296 per base station sector	£28,000 per earth station
Marginal value per 2 x 1 MHz per km^2	£0.76	£0.82 - £47.10	£56

The methodology developed in this report proposes that AIP in shared bands or bands where spectrum could be reallocated between services should be set between the values for a current use and the next highest value. In this case, this would mean setting fees for satellite users near to or at the fixed link or FWA value. Given the uncertainty surrounding the FWA estimates and that FWA spectrum can be used for fixed links we suggest the same value is applied to fixed link and FWA uses. If different values are to apply then the RA will need to use an administrative rule to ensure FWA bands are only used for that purpose. We note that if government wishes to promote the deployment of FWA services, then it could consider the applicability of pricing or use instruments other than spectrum pricing to achieve this objective.

We have reviewed the Agency's algorithms for fixed links and satellite services and have proposed a number of changes. For fixed links we recommend that:

- the regulator carries out an analysis of link capacity in specific bands and areas to ascertain the validity of the proposed pricing differentials for links of differing availability; and
- an equipment technology modifier is not appropriate, assuming that the bandwidth modifier is directly proportionate to bandwidth.

We recommend that the determination of the licence fee for fixed links in a congested area should be based on the following algorithm:

Equation 7.3

Fee = Marginal Value (£ per 2x1 MHz) x bandwidth (MHz) x path length modifier* x frequency band modifier x antenna technology modifier* x availability modifier*.

* Radiocommunications Agency. January 2003. "Fixed links spectrum pricing proposal". v1.1

For fixed satellite services, we recommend that

- Fees are set taking account of the denial area of a typical satellite earth station.
- AIP is not applied in exclusive satellite bands, unless it is possible that the band might be shared with other fixed uses.
- Bands that are defined as congested are consistent with those defined as congested for fixed links and/or FWA use.

We recommend that AIP for scanning telemetry continue to be set on the basis of PMR values.

8 Mobile Services

8.1 Introduction

This section presents marginal values for public and private mobile services.

AIP is not applied to 3G services because their spectrum was either auctioned or is likely to be used on a deregulated basis. The relevant services are therefore second generation cellular, public access mobile radio (PAMR), mobile data / tracking services, paging, private mobile radio and common base stations (CBS). We have not calculated separate values for mobile data, paging and common base station services as this would be unduly complex given the small amounts of spectrum they occupy. The characteristics of these services are broadly similar to PAMR (in the case of mobile data / tracking) or PMR (in the case of CBS and paging), and hence we suggest that PAMR values are applied to mobile data / tracking services, and PMR values are applied to paging and common base station services.

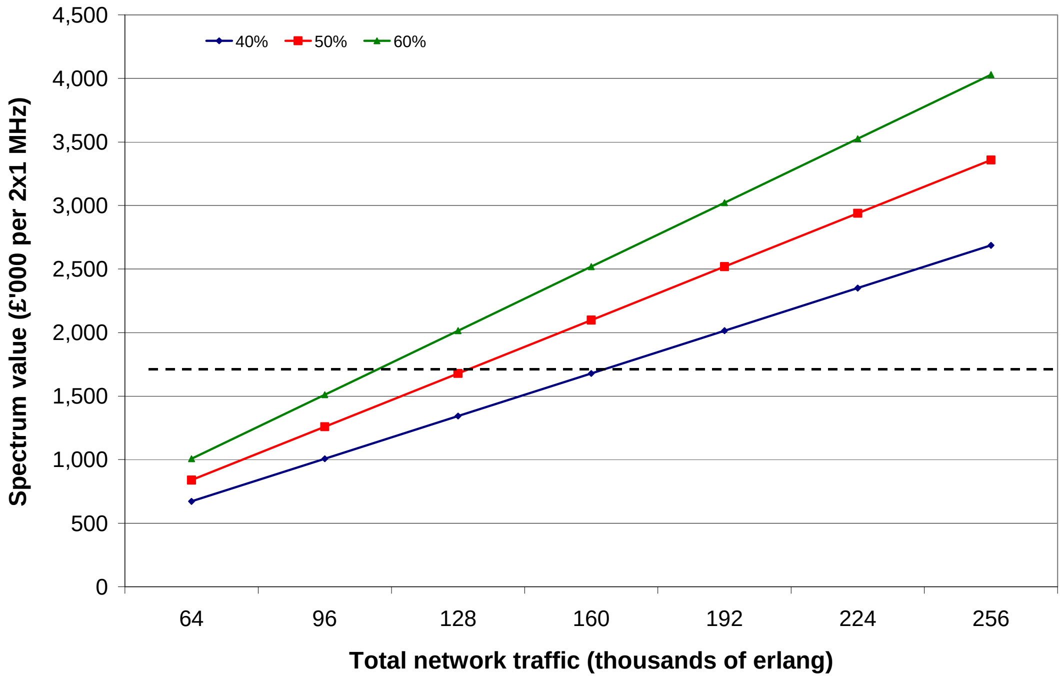
8.2 Cellular Services

The marginal value for cellular services is estimated in Annex 6. The value is based on the infrastructure costs an operator might be save if assigned an additional 2 x 2.4 MHz of spectrum (the equivalent of a single channel per sector assuming a four-cell per cluster, three sector per cell network configuration). It is assumed this spectrum would be used to relieve congestion in urban hotspots. Cost and traffic data come from the LRIC model Analysys developed for Oftel.[79] The network is assumed to be mature (i.e. cell sizes are determined by capacity rather than coverage considerations) and so marginal values are the same for 900 and 1800 MHz networks.

A central estimate of £1.68m/2x1 MHz is obtained, though as can be seen in Figure 8.1 values are sensitive to assumptions concerning the level and density of network traffic. The central value is slightly higher than the Smith-NERA estimate of £1.625m and above the current price of £0.712m/2x1 MHz (900 MHz) and £0.554m/2x1 MHz (1800 MHz). The latter price includes a modifier that takes account of differences in the coverage of 900 MHz and 1800 MHz bands. However we do not consider this to be relevant in the case of mature networks where coverage requirements are already fully met.

[79] Review of the charge controls on calls to mobile, Oftel, September 2001

Figure 8.1 Relationship between spectrum value and traffic volume / distribution

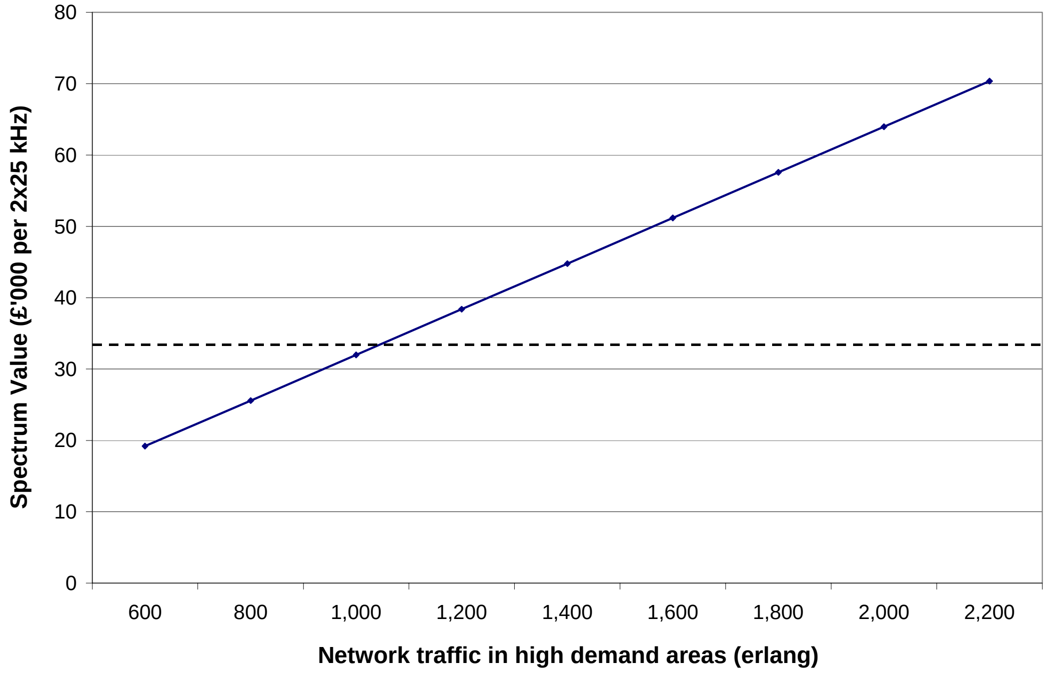


(% figure refers to proportion of traffic carried in areas of highest demand where additional spectrum would be utilised)

8.3 PAMR

The marginal value of spectrum for PAMR services is derived in Annex 7. The approach adopted involves considering the impact of a small increase in spectrum on the infrastructure costs of a PAMR operator. It is assumed that (as in the cellular case) the additional spectrum substitutes for infrastructure in urban hotspots. The marginal value obtained is £32k per 2 x 25 MHz channel. This value is dependent on the assumed level of traffic on the network, as the graph below illustrates (the dotted line shows the estimated value). The value of £32k / 2 x 25 kHz is very similar to the value obtained by Smith-NERA in 1996 (of £34k) but is larger than the current fees of £22k per 2 x 25 kHz.

Figure 8.2 Estimated marginal value of spectrum for PAMR by traffic level



8.4 PMR

8.4.1 Marginal value

The marginal value of spectrum for PMR services is derived in Annex 8 based on the assumption that the least cost alternative to the use of a congested band is to switch to an alternative uncongested band. In practice this might mean, for example, users in a congested band such as VHF mid-band or 450 – 470 MHz bands moving to an uncongested band such as Band III or VHF low band. It is assumed that users must replace existing equipment when they move band and that the existing equipment is half way through its useful life.

Applying this approach gives a marginal value of spectrum of £ 2,578 per 2 x 12.5 kHz for a local system with a notional coverage area of radius 30 km (and sterilised area of radius 60 km). To estimate the marginal value of a national PMR channel, it is necessary to take account of both the physical re-use of the channel and the varying geographic demand for PMR services.

In practice, PMR demand is likely to reflect population. We therefore estimate the value of a national exclusive PMR channel by considering the population within the area sterilised by a PMR system operating in the London area (the most congested part of the country) and scaling this pro-rata to the total UK population. Assuming that the area sterilised has a radius of 60 km and that the population residing within 60 km of central London is approximately 10 million, this implies a multiplication factor of six, resulting in a spectrum valuation of (6 x £2,578) = £15,468 per national 2 x 12.5 kHz channel, or £1.24 million per 2 x 1 MHz. This value is less than the value of £22,000 per 2x12.5 kHz channel obtained by Smith-NERA in 1996,[80] but is larger than the current fee of £9,900.

8.4.2 Congestion and setting AIP

The assumption that PMR demand broadly correlates with population is based on the premise that most PMR licences are held by organisations serving the general public (taxis, utilities, public transport operators etc). A further consequence of using this approach to valuation is that the spectrum value for an individual PMR licence is based on the population residing within the area sterilised by the licensed system. The spectrum valuation will thus reflect the population density in the area concerned, which in turn should reflect the degree of congestion existing at that location. This avoids the need to define specific areas as congested or uncongested.

Note that it is important the price reflects the area sterilised rather than simply the operator's own service area, since this ensures that the full opportunity cost arising from denial of spectrum is reflected. This is particularly important when considering systems which operate in areas where local demand for spectrum is low but congestion exists in an adjacent area, which might be outside the operator's own coverage area but is nevertheless sterilised by the operator's base station.

We recommend that the regulator moves quickly to a situation where it can identify the area sterilised by a licensed PMR system and suggest that an appropriate criterion for defining this area would be the field strength contour currently applied to common base station services. By combining a population database with the regulator's coverage planning tool, it will be possible to determine to a reasonable approximation the population residing within the area bounded by the field strength contour and to set a price accordingly. Such an approach could in principle be applied to all licensed PMR services, whether wide area or on-site.[81] By way of example, Table 8.1 shows the fees that would apply on this basis for a number of hypothetical systems operating on a single, exclusive channel, compared with current fee levels.

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[80] The Smith/NERA values and the current fees are based on the assumption that the least-cost alternative for a PMR operator would be to switch to a PAMR service. They also assumed a reuse factor of 10.

[81] If the RA's planning tools cannot be used to produce the sterilised area for on-site systems then we suggest notional values are used.

Table 8.1 AIP using population in area sterilised for systems using a single exclusive channel

Location	Sterilised area (radius)	Population within sterilised area (estimated)	Current fee	AIP level with a population factor
Central London	3 km (on-site)	1 million	£200	£258
Central London	10 km	4 million	£1,640	£1,032
Central London	40 km	8 million	£1,640	£2,062
Central London	60 km	10 million	£1,640	£2,578
Chelmsford	60 km	8 million	£820	£2,062
Chelmsford	40 km	3 million	£820	£773
Chelmsford	3 km (on-site)	100,000	£100	£26
Carlisle	60 km	300,000	£410	£77

It can be seen that this approach would provide a strong financial incentive for PMR operators to minimise the areas sterilised by their systems, for example by re-engineering their antenna systems. Fees would increase for some licensees with base stations located just outside currently congested or very congested areas, but would be substantially lower than the current uncongested levels for many other licensees whose systems are located in parts of the country where population is sparse.

The current approach used by the RA assumes a standard area sterilised based on a 40 km radius (= 5,000 km^2), although the Agency has stated its intention in the future to take account of the actual area sterilised by individual systems. It is interesting to note that the assumed 5000 km^2 area is less than half the value assumed for common base stations, despite the fact that the two types of system often operate from common sites and are likely in such cases to have similar sterilisation areas. On-site PMR systems have much smaller sterilisation areas (typically 48 km^2) and are subject to a much lower flat rate charge than wide area systems.

In the case of shared channels, which account for the majority of PMR assignments, the price should ideally reflect the proportion of total traffic on the channel that originates from the licensee. Since there is no practical way of determining this level in advance for individual users, we consider that the current approach based on defining broad user categories whose typical usage patterns can be determined from statistical measurement data provides an equitable and transparent means of apportioning fees to users of shared channels. The Agency should therefore continue to use the approach embodied in Schedule 5, part III of the current fees regulation, although the category definitions and threshold levels may be varied from time to time to reflect changes in measured data. We recommend that the regulator reviews the basis for the current fees using its monitoring data.

One possible complication relating to shared channels is that the degree of sharing is likely to vary within an operator's sterilised area, depending on the extent of overlap with other operators' areas. The RA's new planning algorithm for PMR, MASTS, attempts to overcome this by assigning coverage areas on the basis of a desired quality of service (i.e. degree of sharing), but does not extend this approach to the area sterilised. It may therefore be necessary to designate a specific quality of service level for individual channels for assignment purposes.

8.5 Summary

The original Smith-NERA study determined four separate marginal values for PMR, PAMR, cellular and PCN services. However, following consultation with industry the RA decided to adopt a common spectrum tariff unit (STU) for all mobile services, equal to the weighted average of the four individual values, i.e. £1.65 per MHz per km^2. The fee for individual licensees is set by multiplying the STU by the bandwidth in MHz and the area sterilised by the service in km^2.

Marginal values obtained in this study are shown together with the Smith-NERA values in Table 8.2. Cellular is the highest value for the bands it occupies and so the AIP for these bands should be set at the cellular marginal value. For other mobile bands, PAMR and PMR services are generally substitutable in which case the AIP for each of these services should be set between the PMR and the PAMR values. If cellular services can also use these bands then values should be set towards the low end of the range between PMR and cellular values i.e. around £1.3m per 2x1MHz.

Table 8.2 Mobile Marginal Values for a 2x1MHz National Channel

	Smith-NERA (1996)	This study
Cellular – 900 MHz	£1.63m	£1.68m
Cellular - 1800 MHz	£0.81m	£1.68m
PAMR	£1.36m	£1.27m
PMR	£1.75m	£1.24m

In setting AIP for PMR services, we recommend that values are based on the share of the UK population in the area sterilised. This avoids the need to define specific areas as congested or uncongested. We recommend that the regulator moves quickly to a situation where it can identify the area sterilised by a licensed PMR system and suggest that an appropriate criterion for defining this area would be the field strength contour currently applied to common base station services. By combining a population database with the RA's coverage planning tool, it will be possible to determine to a reasonable approximation the population residing within the area bounded by the field strength contour and to set a price accordingly.

In the case of shared channels, we consider that the current approach, based on defining broad user categories whose typical usage patterns can be determined from statistical measurement data, provides an equitable and transparent means of apportioning fees to users of shared channels. We recommend that the regulator reviews the basis for the current fees using its monitoring data.

9 Broadcasting Services

9.1 Introduction

AIP is designed to provide optimal incentives for licensees to use spectrum efficiently. In addition, the Government's response to the Independent Spectrum Review made specific reference to the promotion of analogue to digital switchover, and in the case of digital terrestrial television, the promotion of more efficient use of available spectrum.

We have approached broadcasting using the general methodology developed to promote efficient spectrum use, and note that this is consistent with the Government's objective of switchover (the latter because spectrum pricing will encourage digital switchover to the extent that the spectrum requirements for a given service level are reduced by using digital rather than analogue technology). We calculate the opportunity cost of spectrum by applying the general methodology which considers the cost of maintaining existing output levels (or coverage) for marginal reductions in both analogue and digital spectrum. The method is consistent with the Government's objective for digital terrestrial television of the promotion of more efficient use of available spectrum.

In Section 6 it is recommended that AIP for sound broadcasting should be designed to promote efficiency and not switchover objectives per se. However, as noted above AIP is consistent with promoting switchover. In Annex 2, we noted that technical and policy constraints limit the extent to which analogue sound broadcasters can modify their spectrum use. However, applying AIP would ensure that the opportunity cost of spectrum is taken into account in wider policy decisions including consideration of whether the benefits of relaxing existing constraints exceed the costs. Furthermore, in the future users of digital audio spectrum may have greater flexibility in their spectrum use, e.g. by re-configuring transmitters within the coverage area to reduce exported interference.

In estimating the opportunity cost of spectrum for broadcasting we have treated spectrum as an input into the production process in line with the general methodology developed in this report. We considered carefully the question of whether consideration of externalities or wider social benefits imply that this approach should be modified in any way and concluded that such considerations do not imply any change of approach, consistent with efficiency. The detailed reasoning for this conclusion is set out in Section 2.6. In brief, the argument is simple – the promotion of the efficient use of spectrum via spectrum prices based on opportunity cost can, consistent with the promotion of overall efficiency, be kept separate from decisions over the promotion of particular outputs from broadcasting via other policy instruments, such as the TV licence fee and arrangements for funding the BBC, and coverage (i.e. universality) public service and other content obligations imposed on broadcasters. To draw an analogy, the price charged for electricity used in broadcasting is not subsidised because broadcasting is the output.

9.2 Television

The UHF broadcasting spectrum is congested in the sense that there is potentially excess demand from existing and alternative uses. Spectrum occupied by analogue TV services could be used for: additional analogue TV services, digital TV services, PMSE, mobile datacasting and possibly also conventional mobile services (commercial or public safety).

We value UHF spectrum to an analogue broadcaster (now) and a digital broadcaster (following switchover) by considering the impact on coverage of having fewer channels and then estimating the net cost to broadcasters of replicating the original level of coverage (output) with satellite/cable services. The analysis is done on a per channel group (analogue) or per multiplex (digital) basis. In practice broadcasters will enjoy economies in clubbing together and jointly providing households with alternative means of reception (e.g. satellite dishes) as these can be used to receive multiple services. We also note that the cost to one broadcaster in providing alternative means of delivery would facilitate reduced spectrum use by all broadcasters in the coverage area.

It is assumed that the channel grouping corresponding to the lowest incremental coverage would be chosen and that in parts of the coverage area reception would be available from adjacent transmitters (though reception by portables may be lost and re-alignment or replacement of aerials may be needed in some cases). Current penetration of cable and satellite, estimated at 30% of TV households, is assumed.

For digital, we consider a reduction from 6 channels per multiplex to 5 channels per multiplex, for the two public service multiplexes post-switchover. This option was considered in the 2002 DTI/DCMS consultation on the Principles for DTT Spectrum Planning[82] and was estimated to correspond to a reduction in population coverage from 95% to 90%. Cable and satellite penetration of 35% at switchover is assumed.

For analogue we estimate a cost per MHz per annum of approximately £1 million, while for digital we estimate a cost per MHz per annum of approximately £1.2 million. In the case of analogue services, some households may be able to receive services over DTT and this may reduce our estimates, depending on the extent of DTT coverage and whether households would need new aerials as well as a set top box. However, the estimates make no allowance for the loss of reception for second and third sets in each household, which would tend to increase the value.

To provide a check on the reasonableness of the values estimated, we note that a marginal use of the UHF TV spectrum could be PMSE, as PMSE use will be displaced from the existing interleaved channels as digital services are rolled out and there is currently rapidly growing demand for spectrum from PMSE services. We suggest in Section 10 that PMSE use below 3GHz should be priced at the value for PMR spectrum i.e. at £1.28m/2x1MHz. This taken together with the estimates for the marginal opportunity cost of analogue implies a value around £1-£1.2 m/MHz. We note that these estimates could be refined if detailed geographic data on cable and satellite penetration, satellite installation costs and transmitter infrastructure costs were obtained.

An indication of the incentives to migrate to digital transmission is provided by estimating the cost of providing national coverage for the four analogue channels. With analogue 44 channels are required at 8MHz per channel, costing £352 million per annum (at £1million per MHz). With digital around 9 channels at 8MHz per channel would be required at a cost of £86.4 million per annum (at £1.2 million per MHz), a saving of £265.6 million per annum.

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[82] Available at http://www.digitaltelevision.gov.uk/pdfs/spectrum_planning_digital_TV.pdf

9.3 Sound Broadcasting

There is excess demand for sound broadcasting licences in the FM band (88-108 MHz) in some locations, demand in the AM band is static and demand for digital licences is weak in most areas.[83] Pricing would therefore only seem appropriate for FM spectrum at present.

We have not found a direct means of calculating the marginal value of spectrum using the least cost alternative methodology. This is partly because radio licensees are not permitted to modify the technical characteristics of their licences. In addition, the approaches used for television do not apply because an equivalent service cannot be offered using satellite or cable technology since radio is often listened to in indoor portable or outdoor mobile modes, neither of which is likely to be possible from a satellite (though, for example, satellite car radios exist in the US). There could in principle be demand for the FM spectrum from PMR services, but this is unlikely in practice because of the large size of PMR equipment at these frequencies and the potential interference from sound broadcasting services in neighbouring countries.

An alternative approach would be to examine market information on the value of radio licences. Data on the profitability of the last radio station to enter a congested market (e.g. London) could be used to estimate the value of the spectrum based on the “supernormal” profits made by the station. However, data on station profitability is not generally publicly available.[84] Some information is available for a recently traded station in London, LBC. In 2002, LBC had an annual turnover of £4m and losses of £1.7m and was sold in September 2002 to Chrysalis Radio for £11m.[85] The fraction of the £11m might be attributed to the value of the spectrum is debateable, as no doubt part of the payment reflects the value the buyer believes it can add to the station’s operations and rental values associated with other non-spectrum assets. In this case, the annual profitability of the station provides no guidance as to the spectrum value. We note that it is often the case that “marginal” stations are unprofitable for long periods of time and so analysis of available profit data may not be useful in valuing sound broadcasting spectrum. We have not therefore estimated marginal values for sound broadcasting services.

9.4 Summary

We have produced estimates of the marginal opportunity cost of TV spectrum based on calculations for both analogue (now) and digital spectrum (after switchover). The estimates lie in the range £1-£1.2 million. An indication of the incentives to migrate to digital transmission is provided by estimating the cost of providing national coverage for the four analogue channels. With analogue 44 channels are required at 8MHz per channel, costing £352 million per annum (at £1million per MHz). With digital around 9 channels at 8MHz per channel would be required at a cost of £86.4 million per annum (at £1.2 million per MHz), a saving of £265.6 million per annum.

Lack of reliable data has meant that we have not been able to estimate values for sound broadcasting using either the least cost alternative methodology or an approach based on

[83] Digital licences recently tendered by the Radio Authority have generally had a single applicant and so we conclude that congestion is unlikely to be an issue for some time in the DAB band 217.5-230 MHz.

[84] Most stations are owned by companies with a number of stations and/or other activities.

[85] LBC – from 1973 to today, Media Guardian, 4 December 2002; Chrysalis confirms LBC bid, Media Guardian, 25 September 2002.

station profitability. We note that one way to reveal the value of a marginal FM radio station would be to auction the licence and allow trading, subject to any content controls.

10 Other Services

10.1 Introduction

This section discusses the derivation of marginal opportunity costs and their application in setting AIP for aeronautical services, defence, maritime services, programme making and special events and science services. With the exception of aeronautical services, the values applied are those obtained for fixed, mobile and broadcasting services depending on the potential substitute use of the spectrum.

10.2 Aeronautical Communications

10.2.1 Current Situation

Aeronautical services were not included in the original Smith-NERA pricing study and are not currently subject to AIP. Licence fees are currently set on a notional cost recovery basis at levels that fall well short of the AIP levels applied to other, comparable services such as PMR. Historically, the case for applying AIP to aeronautical mobile services was weak because of the international, exclusive nature of the frequency bands concerned and the lack of congestion. However, the high and continuing growth in aviation traffic in recent years, combined with the emergence of new data communication requirements has prompted demands for additional spectrum for aeronautical mobile spectrum. These demands are expected to be addressed at the next World Radiocommunication Conference, reflecting growing concern within the aviation community about future congestion within the existing aeronautical bands, in particular within the VHF band (118 – 137 MHz).

10.2.2 Options for improving spectrum utilisation

Technology currently exists to reduce the radio frequency bandwidth required for VHF aeronautical mobile communications from 25 kHz to 8.33 kHz. The international civil aviation regulatory bodies have already implemented a requirement for commercial aircraft flying above 24,500 feet to upgrade their on-board equipment to the new narrowband (i.e. 8.33 kHz) standard. The main air traffic control provider in the UK, National Air Traffic Services (NATS) plans to upgrade its ground stations but has not yet done so. We understand there are no plans for the general aviation community to upgrade at this stage.

Adoption of the new standard would result in a substantial reduction in the spectrum utilisation for each ground station. Although the reduction in bandwidth is 3:1, the reduction in spectrum utilisation will in practice be less than this once frequency re-use considerations are taken into account. For the purpose of deriving illustrative values we have assumed a reduction of 50%, though the eventual figure may be lower. This would be sufficient to accommodate much of the anticipated growth in demand. There is therefore a good case for the application of AIP to incentivise the adoption of narrow band technology by the aviation community.

10.2.3 Marginal value

Marginal values for the VHF aeronautical mobile band are estimated in Annex 10, based on the cost of upgrading to narrowband equipment. A range of values are presented, based on various assumptions about the cost of upgrading ground stations other than air traffic control. The values range from £11,700 to £41,210 per 25 kHz channel, or £468,000 to £1.65m per MHz. We note that there is considerable uncertainty concerning the estimated cost of ground stations used to produce these values.

10.2.4 Setting AIP

Since aircraft require access to the full band it is not possible to apply a fee on a per-channel basis, and in any case each aircraft is only likely to be operational for a small proportion of the time compared to a typical ground station. We would therefore propose the marginal value derived above be applied to each ground station in areas that are deemed to be congested (such areas should be identified in conjunction with the CAA).

However there may also be some merit in also reviewing fees for aircraft as all parties may need to be given an incentive to change otherwise the un-priced party could seek to block change through political processes. One solution may be to introduce a two-tier pricing regime for aircraft radio licences, retaining the existing cost-based fee where 8.33 kHz equipment is deployed and applying a premium for other equipment. As a minimum we would suggest that the premium should reflect the cost differential between narrow band and conventional equipment. If it is assumed that 8.33 kHz technology represents the most efficient viable use of the spectrum a similar approach may also be appropriate for ground stations on the basis that there is no alternative to radio communication

10.3 Aeronautical Radar and Radionavigation Systems

10.3.1 Congestion

Most radar bands are internationally designated exclusively for this application and do not experience congestion, although according to the Civil Aviation Authority (CAA) certain bands could suffer congestion in the future due to emerging demand for new radio-navigation and communication services. In addition, Channel 36 in the UHF broadcasting band is a UK only allocation and could alternatively be used for broadcasting purposes.

10.3.2 Marginal values

So far we have not been able to obtain reliable information on radar costs and so have not been able to derive values directly. In the case of Channel 36 the marginal value of spectrum derived for TV broadcasters (of £0.5-1m/MHz) could be applied.

10.3.3 Out of band emissions

AIP could be applied to radars to give incentives to limit the extent of out of band emissions that effectively deny spectrum use in adjacent bands. On further discussion with the aeronautical division in the Agency we have concluded that further technical work is required before a base-line of acceptable out of band emissions can be established for all radars (old and new). Only once this technical work has been undertaken and a base-line established can the possibility of pricing be considered. We therefore do not address this issue any further within this study.

10.4 Defence

Details of the nature and extent of use of spectrum by the defence services are not known and so it is not possible to comment on the extent of congestion or to estimate marginal spectrum values for defence applications per se.

However many bands used by the defence forces would be demanded by civil uses were they to be made available. NATO bands are excluded from consideration because these bands could not be reallocated to other uses (except potentially for public safety applications as in the case of the 380 – 400 MHz band). In the case of UK specific defence allocations reallocations to civil uses are possible e.g. this includes GSM spectrum in some areas. The marginal values for these civil uses are therefore relevant to estimating the AIP for defence spectrum.

We do not know if this gives values that are too high or too low as defence values are not known, but our method suggests that values should not be set above the corresponding civil value. These values should only apply if the civil use experiences congestion. Hence it is proposed that the existing principles used to price defence bands are continued, namely that the bands should attract a charge equal to the price that applies to the potential civil use of the band.

By way of illustration, the value of military spectrum above 3 GHz could be set with reference to the current utilisation of the 13 GHz band. Table 10.1 shows the number of links of various bandwidths in the 13 GHz band, the number of congested links (we have assumed for simplicity that this is 50%) and the cumulative marginal value based on £132 per 2 x 1 MHz per link:

Table 10.1

Link bandwidth	3.5 MHz	7 MHz	14 MHz	28 MHz	Total
No of links	776	1,456	324	2,480	
Congested Links	388	728	162	1240	
Marginal Value	£0.18m	£0.67m	£0.30m	£4.58m	£5.73m

The total bandwidth available in the 13 GHz band is 224 MHz; this suggests that the current cumulative marginal value is around £25,580 per 2 x 1 MHz (£5.73m / 224), based on the estimated number of congested links currently assigned in the band.

Where defence use shares spectrum with civil applications and constrains the civil use of spectrum[86] then clearly the fee should be shared between defence and the other users. It is important not to double count use of spectrum in such circumstances. A simple way of doing this is to apportion the national fee based on the share of bandwidth multiplied by area sterilised.

10.5 Maritime Communications

10.5.1 Congestion

Most bands used by maritime communications are international exclusive bands. The extent of congestion in the bands is not known and furthermore it is not feasible to charge foreign vessels for the use of the spectrum. In addition, ships' licences entitle access to all channels and do not provide an opportunity to "economise" on spectrum use. One exception is maritime business radio which uses a UK only allocation in the 157 – 163 MHz range and for which we understand there is anecdotal evidence of congestion on parts of the south coast. This frequency range is shared with PMR (VHF high band), which will be subject to AIP in congested areas.

[86] There are circumstances where there is no constraint, for example, because the defence use is only in remote areas where there is no civil use.

10.5.2 Setting AIP

As maritime business communications use spectrum in a PMR band it is proposed that the PMR AIP should be used for this application in congested locations.

10.6 Programme Making and Special Events (PMSE)

10.6.1 Nature of spectrum use

PMSE encompasses a range of applications the most important of which are radio microphones, talk back (continuous base station communication to mobile terminals), video links and audio links. It uses a variety of spectrum bands including the 450 – 470 MHz band, 518—614 MHz (TV channels 35-38), 766-862 MHz (TV channels 58-69), various 2GHz bands, 3.4-3.6 GHz and bands at 5, 7 and 10 GHz.

The majority of PMSE use differs from other use in that it is temporary in nature. In many cases, assignments are not guaranteed to be free from interference, either from other PMSE users or licence-exempt equipment that may operate in the same band (although the Agency's licensing agent for PMSE, the Joint Frequency Management Group (JFMG) endeavours to co-ordinate assignments in order to minimise interference). In yet other cases, such as the use of the TV broadcast bands on a localised basis, it is fair to say that the use does not itself lead to spectrum denial since it would not be feasible for other applications to use the band without jeopardising the protection of the TV transmissions. It should be noted that this situation will change when analogue TV services are discontinued and at that time it will be necessary to review the use of this spectrum for PMSE applications.

10.6.2 Setting AIP

Current fees for PMSE are based on a methodology put forward by Smith-NERA in their 1999 report on spectrum pricing policy.[87] The report suggested that in setting fees it would be appropriate to apply the mobile radio spectrum tariff unit (STU) to assignments made below 1 GHz and the fixed link STU to assignments made above 1 GHz. In general this would mean setting fees by reference to the bandwidth occupied and the geographical area sterilised for use by others. A comprehensive set of fees have been established for individual classes of use, based on this principle and in association with the JFMG.

Given the complex and varied nature of PMSE applications, we do not propose any significant change from the current methodology. However we suggest that the breakpoint at which fixed services rather than mobile are used as the comparator service should be shifted from 1 GHz to 3 GHz. Where channels are assigned on an exclusive basis over a local, regional or national area, we recommend that the same approach to fee determination is taken as for PMR services. This may result in a substantial fee increase where the spectrum concerned lies within a range that could be used by PMR services and is currently considered to be congested, such as the 450 – 470 MHz band. Currently, a regional channel of 12.5 kHz bandwidth covering the whole of the London area in this band would cost a PMSE user only £180 per year. If the assignment were subject to the same proposed fee as a PMR assignment the fee would increase to £1,289 (half the value for a 2 x 12.5 kHz PMR channel in central London sterilising an area with a population of 10 million).

[87] Spectrum Pricing Study: Final Report, Smith and NERA for the Radiocommunications Agency, 1999.

10.7 Science Services

The services considered here are radio astronomy and earth exploration.[88] Both services have a number of internationally allocated bands which cannot be used for other services and so have a zero opportunity cost as there is no congestion between existing users. AIP therefore must focus on UK specific bands which could be used by alternative services which have an excess demand for spectrum. As these uses are generally passive they are not licensed. Hence pricing can only be applied if the users opt for recognised spectrum access (RSA).

In this case we cannot estimate directly the marginal value of spectrum to the user and so suggest that as for defence use pricing should be applied based on the AIP for the alternative potential use of the band, in those locations where the latter is congested. This would mean applying mobile values to spectrum below 3GHz, except in the case of channel 38 of the TV band where the value for broadcasting use should apply. Above 3 GHz the fixed link value should be applied.

The AIP should take account of the area and bandwidth sterilised by requirements to protect the radio astronomy service and if a band is shared then the AIP should be pro-rated by bandwidth multiplied by area sterilised. For example, in the case of Channel 38 it is proposed that the fees would be based on an algorithm that reflects the current protection requirements as applied in practice and not the current exclusion area of 3km radius.

10.8 Summary

It is recommended that AIP are applied to the VHF aeronautical communications band (118-137 MHz). Illustrative estimates of marginal values for this spectrum range from £11,700 to £41,200 per 25 kHz channel. It is suggested that AIP is applied to ground stations and that aircraft fees are also adjusted so that there is a premium for equipment using 25 kHz channels based on the cost differential between narrowband and conventional (i.e. 25 kHz) equipment.

While there appears to be a good case for pricing use of spectrum by aeronautical radars in bands that are expected to become congested, we have not been able to obtain reliable information on radar costs and so have not been able to derive values. In the case of Channel 36 the AIP for TV broadcasters could be applied.

We recommend that congested maritime communications bands should be priced based on the AIP for PMR.

For defence, programme making and special events and science services we recommend that above 3GHz the fixed link AIP are applied and below 3GHz either the AIP for mobile or broadcasting services are applied depending on which of these services is expected to use the spectrum under consideration. AIP should only be applied in those bands where the fixed, mobile or broadcast use experiences congestion and where use of the spectrum by these services would be constrained by defence, PMSE or science service use. To avoid double counting in shared bands, the national AIP should be apportioned based on the share of bandwidth multiplied by the area sterilised.

[88] The meteorological service is part of the Ministry of Defence and so pricing of its use of spectrum is dealt with using the approach proposed above for the defence bands.

11 Implementation Issues

11.1 Introduction

This section addresses the following implementation issues:

- Should there be a transition to the full AIP values?
- What should be the approach to reviewing AIP?
- Should discounts or exemptions be given to any particular class of licensees?
- Should AIP vary with the degree of congestion?
- How should charges in uncongested bands or areas be set?
- What data should be collected to monitor the impact of spectrum pricing?
- How should the impact of AIP be tested?

11.2 Transition path

When AIP was introduced in 1998 initial values were set at roughly half the values proposed by the RA (which were in turn half the values estimated by Smith-NERA) and a four year transition to the proposed values was implemented. A transition path was implemented because there was a concern that prices might be too high and that this would lead to under-use of spectrum. It was also recognised that a clear transition path to the proposed values would give users incentives for efficient use of spectrum. In the event prices do not appear to have had a significant impact on behaviour.[89]

The approach we have adopted is deliberately conservative, although if the marginal values we have derived are applied there could be substantial increases in fees for some users. This is somewhat inevitable given the original Smith-NERA values were halved to obtain the current prices. However, given that thus far spectrum pricing appears to have had little impact on behaviour there would seem to be a good case (on efficiency grounds) for moving quickly to new values particularly if trading is not introduced immediately.

11.3 Reviewing AIP

The proposed approach to setting AIP is intended to move spectrum use towards a more efficient outcome but is unlikely to deliver the optimal outcome at any point in time. It assumes that one iterates towards the optimum recognising that the optimum itself is moving over time as demand and technology change. This raises the question of the frequency with which AIP should be reviewed. Factors affecting the choice are:

- The time taken to undertake a pricing review;
- The time taken to collect a useful time series of data about changes in spectrum use;
- The volatility of demand for spectrum;
- The need to give licensees some certainty concerning the charges they will pay; and
- The timing of the introduction of spectrum trading.

[89] Spectrum Pricing Effectiveness Review, Licensing Policy Unit, Radiocommunications Agency, February 2002.

A pricing review takes up to one year – 3-6 months to do the work and the same again for consultation - and changes can then be implemented in the fees order for the following year. This suggests a minimum of two years between reviews.

We would expect that at least 3-4 years data would be required to see any impact from a change in pricing, given users' behaviour is likely to be slow to change because of their existing investments. A pricing review would have to start at least a year in advance of implementing new prices and so this suggests there should be at least 5 years between reviews. This would also give users a reasonable degree of certainty around which to plan.

Spectrum trading is likely to be introduced in the next 2-3 years and its interaction with AIP will need to be taken into account in determining the frequency of pricing reviews and their conduct. Uncertainty about the level of AIP could depress traded prices and the number of trades. Infrequent revisions of AIP would help reduce uncertainty in the near term. However, if the demand for spectrum is changing rapidly then this could argue for shorter review period so that prices do not get too out of line with market conditions. About a five year review period would seem to offer a reasonable compromise.

The process for conducting reviews also needs to be considered, as licensees need to be given some assurance that the government will not opportunistically increase prices. This might be achieved if the regulator:

- Commits to a consultation process for any review of prices;
- Commits to a pricing methodology;
- Commissions an independent audit of the prices calculated using the methodology. The audit would check that the assumptions underpinning the prices were reasonable; and
- Monitors the impact of pricing and regularly reports evidence on the efficiency benefits achieved by pricing (see below).

11.4 Discounts and Exemptions

It is sometimes argued that certain classes of users should receive discounts or be exempted from spectrum pricing. In Section 6 we indicated those services for which AIP is not appropriate because the opportunity cost of spectrum is zero and/or because of policy impediments (see Table 6.1). We also concluded in Section 2 that AIP should be set so as to promote spectrum efficiency and that other policy instruments should be used to promote other policy objectives.

It has been suggested to us that there may be a case for discounts for new services on the grounds that operators of these services are likely to be cash constrained and so pricing would act to inhibit the roll-out of services that may in time be commercially viable. It is our view that the market is in general the best judge of whether services are likely to be commercially viable and so if a provider of a new service is unable to finance the cost of its inputs including spectrum then it should not be granted special access to use of spectrum.

It is important to note that the framework we have used to assess whether AIP should be applied takes into account government policy priorities. In particular, if government wishes see particular services of uncertain viability rolled out in order to meet particular policy objectives, then we would expect this be clear at the outset and that the services in question would be exempted from AIP for a period of time (though users may still have to pay charges to cover administrative costs).

The government currently gives discounts to charities involved in safety of life activities (e.g. the lifeboat service). This can be justified on the grounds that use of spectrum generates a social value which exceeds the user's ability to pay and so spectrum pricing could result in too little of this activity being provided. This argument is persuasive if government cannot or will not use other policy instruments to ensure the socially optimal level of service is provided.

11.5 AIP and the Level of Congestion

At present charges for private mobile radio services are set based on the degree of congestion in an area with different values for heavily congested (i.e. London), moderately congested (i.e. Manchester and Birmingham) and uncongested areas. For fixed links there is only a distinction between congested and uncongested areas. Fees for uncongested areas are discussed in the next section.

We have suggested (in Section 8) replacing the distinction between heavily and moderately congested areas for PMR with an approach based on the fraction of the UK population living in the area sterilised by the licensed system. This has the advantages of avoiding the need to define specific areas as congested or not and provides strong financial incentives for users to minimise the areas sterilised for transmitters located in and near to large population centres.

11.6 Approach to Setting Administrative Charges

In bands or locations where spectrum is uncongested administrative charges and not AIP should be applied. AIP can only be justified on efficiency grounds. It has been suggested to us that there may be a case for applying fees related to but less than the full opportunity cost of spectrum in areas not experiencing congestion. The intention would be to encourage use of spectrally efficient equipment and thereby reduce the likelihood of future congestion. However, this approach risks setting fees at too high a level in areas and bands that may never become congested and, more generally, could have the effect of reducing spectrum use in areas/bands where spectrum is plentiful thereby reducing welfare and efficiency. These costs need to be offset against any possible benefits from reducing future congestion. The latter seems likely to be small given that if congestion does develop in currently uncongested bands then this can be taken into account in the periodic resetting of AIP.

The Authorisation Directive requires that administrative charges levied on spectrum licensees should recover spectrum management costs, be objective and transparent. National regulators are required to publish an annual overview of administrative costs and the total sum of charges collected. The total sum of charges must cover the costs of spectrum management, however, we understand that charges for individual services do not need to be cost reflective.[90]

11.6.1 The Structure of Charges

For services subject to AIP, the current fees set in uncongested areas are a fraction of the AIP. For services not subject to AIP, fees are loosely related to the RA’s management costs

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[90] Section 401 (3) of the Communications Act 2003 states that Ofcom may retain the costs of carrying out spectrum functions and the amounts retained must be objectively justifiable, transparent and proportionate. Ofcom must also make a statement of principles under which they retain amounts received under the Wireless Telegraphy Act 1998.

before 1998. In total the charges more than recover the RA's costs of managing the spectrum.[91]

All licensees, whether using spectrum that is congested or not, should pay charges that recover the costs to Ofcom of managing the spectrum on the grounds that they cause these costs to be incurred. This could be done in two ways:

- Levying cost recovery charges separate from and additional to AIP; or
- Levying cost recovery charges for uncongested spectrum and applying AIP elsewhere.

A separate cost recovery charge has the advantages of clarity and efficiency in that users pay for the spectrum management costs they impose. The second approach has the advantages of simplicity and continuity with the current system.

11.6.2 Basis for Charges

If administrative charges are set based on the costs of spectrum management then cost measurement issues need to be considered. At present only 25% of the RA's costs can be directly attributed to particular services. The remaining 75% of costs are not attributed either because they are common to many services or because they are incurred in advance of services being introduced. For example, many man-years of effort goes into securing international / European allocations, undertaking co-ordination and co-existence assessments and developing the policy framework for the introduction of new services.

In principle a variety of approaches might be used to allocate overhead costs to service categories including:

- a proxy for willingness to pay (e.g. value of spectrum used);
- the number of licences;
- MHz allocated to the service and then either number of licences within each service group, the total bandwidth allocated to each group or the total spectrum utilisation by each group (expressed as a product of bandwidth in MHz and area in km^2);
- share of variable spectrum management costs.

There are issues with all of these approaches:

- An approach based on the value of spectrum relies on there being a complete set of values for all services. This will not be the case.
- Number of licences imposes relatively high costs on users of small amounts of spectrum or spectrum over a small area as compared with large users. While this may not be regarded as fair it is administratively simple and should give reasonably stable values. There is also the complication that defence services are not licensed and so would not bear any of the RA's overheads.
- Allocation by bandwidth by contrast could mean that defence bears a large share of the regulator's costs. Allocating costs by number of licences is administratively simple but may result in volatility in charges if the number of licences per service

[91] In 2003, the RA's income totalled £138m and its operating costs were £71m.

changes rapidly – up or down. Allocation of costs by bandwidth and area would be more stable, but is more complex to implement.

- Share of variable management costs is straightforward but as only 25% of the RA's costs are allocated to particular services this could result in sharp changes in the costs borne by different services/licence categories.

Alternatively, it could be simpler to recover overhead costs through AIP and set cost related charges based on the variable cost element. These issues can only be resolved once cost and licence data are analysed and their materiality assessed. If cost related charges are applied then decisions will be required concerning the service or licence categories to which these should be applied. Starting with the current licence categories including those used to set AIP has the advantage of administrative simplicity.

An approach that is administratively simpler than those discussed above would be to set fees for a service in uncongested locations as a fraction of the AIP. While it may be expedient initially to set fees in uncongested areas as some fraction of AIP the link should not be perpetuated over time. Otherwise fees in uncongested areas will increase when AIP are increased, although there may be no reason to do so on efficiency grounds. This could have the effect of reducing use of spectrum in areas where it is plentiful thereby reducing efficiency and welfare. It is also important that there is a large differential between fees in congested and uncongested locations so that users have a strong incentive to locate in the latter rather than the former.

11.7 Monitoring the Impact of AIP

Spectrum pricing was first introduced in 1998 and prices were initially set at levels substantially below the Smith-NERA recommendations and only recently have approached half the Smith-NERA recommended levels. It could be expected that the impact of the policy would be small, in the sense that there would be little change in spectrum use, because of low prices.

Even where spectrum usage has changed since 1998 it is difficult to assess the impact of AIP because of the lack of suitable data. While the RA has comprehensive licensing data, it has proved difficult to link causally changes in numbers of licences or bandwidth used to the introduction of spectrum pricing. Evidence on changes in spectrum use in fixed link bands suggests that spectrum pricing may have encouraged the use of narrower bandwidth equipment and/or higher frequency bands, however, changes in the competitive and market environment (e.g. growth in demand from mobile rather than fixed network operators) appear to have been more significant in determining changes in mobile spectrum use.[92]

Many changes in spectrum use appear to be the result of changes in the market and competitive environment facing users. Disentangling the impact of these and other non-price factors is problematic without sufficient data to adopt a statistical approach to isolating the effects of different factors.[93]

To address these issues we suggest that the following data is collected for each spectrum use from a representative sample of users:

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[92] Spectrum Pricing Effectiveness Review, Licensing Policy Unit, Radiocommunications Agency, February 2002.

[93] In principle one could compare changes in spectrum use in the UK with changes in countries which have not implemented AIP, however, this is likely to be even more difficult than making comparisons of UK data across time because of country specific factors that will affect spectrum demand.

- spectrum use such as frequencies used, technology used and location of use;
- competing communications media that might be used and an indication of their costs relative to the current spectrum use;
- measures of the scale of activities (e.g. turnover);
- reasons for changes in spectrum use;
- alternatives (e.g. additional base stations or switch to public network) used where spectrum is returned; and
- alternative communications medium used in circumstances where spectrum has been returned and the price of the alternative.

The purpose of collecting this data would be to provide the information required to assess the impact of AIP on spectrum demand. While information on reasons for changes in spectrum use is not strictly required to estimate demand equations, this information should prove useful in understanding demand drivers. Also, if demand equations cannot be readily estimated from the data, information on reasons for changes in use could be useful in assessing the impact of the pricing policy using techniques other than econometrics (e.g. cross tabulations or cluster analysis). Ideally data collection would begin in advance of the implementation of any new pricing regime so that the full impact of the change can be assessed.

If we take the example of PMR use, then we suggest selecting a random sample of users from the RA's database of licensees and sending those selected a questionnaire every year that asks questions on the topics listed above. Ideally the same sample would be used every year (i.e. it would be a panel) and if there were drop-outs these would be replaced with other users with similar spectrum use profiles.

We anticipate that this approach could be used with other categories of service where there are many users, such as fixed links, PMSE and satellite users. For services where there are very few users (e.g. TV broadcasting, cellular and PAMR services) either all users could be surveyed or data could be collected in a more ad hoc manner if the regulator's staff dealing with these users are likely to be made aware of changes in spectrum use caused by the change in pricing.

11.8 Testing the Impact of Pricing Proposals

The regulator will need to undertake a cost/benefit analysis of any proposed changes in pricing. The net benefits of a change in spectrum pricing are captured by the sum of changes in transaction costs, consumer surplus and producer surplus. The second order impact of a change in spectrum pricing on government revenues, and so on the level of general taxation, is not counted.[94]

The assessment of transaction costs should be relatively straightforward, as these comprise the administrative costs incurred by government and users in implementing the new price regime. These costs could be estimated using data on the RA's implementation costs and information on the actions users would need to take under the current and proposed pricing systems to calculate their licence charges. A money cost could be estimated by imputing a value to changes in time expended.

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[94] General taxation involves a deadweight loss in the wider economy in terms of altered work, savings and consumption decisions. Revenue raised by spectrum pricing could offset this deadweight loss.

The assessment of consumer and producer surplus is however more complex. There are three cases to be considered:

- non-marketed services;
- marketed services for which spectrum use is a constraint on production;
- marketed services for which spectrum use is not a constraint on production.

11.8.1 Non-market services

Non-marketed services are provided free at the point of use and are publicly funded. Non-marketed services that use significant amounts of spectrum include defence, public safety and emergency services, publicly funded broadcasting, science services and publicly funded maritime and aeronautical services.

Producer surplus is not relevant in the case of these services. A change in AIP could however lead to changes in consumer surplus, depending on any associated changes in government funding and constraints on service provision.

For simplicity consider two extreme cases:

- Full compensation for the change in spectrum prices. We assume this is provided so that users keep output levels and quality constant, though in doing this the user may economise on spectrum use (i.e. may use a different mix of inputs to produce the given output level), in which case spectrum would be released for other users/services.
- No compensation for the change in spectrum prices, in which case output and quality levels may be changed as well as the input mix. Again spectrum may be released for other users/services.

In the first case there is no direct change in consumer surplus for the service in question, though if spectrum is released this may be redeployed and thereby increase consumer (and possibly also producer) surplus. In the second case, there will be a reduction in consumer surplus for the service in question and offsetting benefits (consumer and producer surplus) from spectrum released for new services.

11.8.2 Marketed goods for which spectrum use is a constraint on production

When spectrum use is a constraint on production,[95] a change in the spectrum price may result in a shift in the supply curve causing a change in consumer and producer surplus. In this case where no spectrum is returned to the regulator, there are no potential gains from reallocation to other uses.

If spectrum is reassigned between different users with those who value the spectrum most receiving more spectrum then productive efficiency should improve, the supply curve would shift down and there could be gains in producer and consumer surplus.

[95] Examples of services which may fall into this category include cellular telephony, commercial TV and PMR and fixed links in London.

11.8.3 Marketed goods for which spectrum is not a constraint on production

Where an available spectrum band is not a constraint on production in its current use[96] spectrum pricing would raise unit input costs and increase the price of final services to consumers. Demand for spectrum would fall, but without benefits within the confines of the existing use as spectrum is not a constrained input.[97] Consumers of the service in question are made worse off by spectrum pricing since their demand is reduced. Additional revenue collected from consumers which in turn is passed to producers and onto the regulator via the spectrum charge is a transfer and so there is no associated gain or loss of welfare. Hence the net effect is a loss of welfare known as the deadweight loss.

Offsetting this loss some spectrum may be priced out of its existing use and returned to the regulator. (Indeed this would be a rationale for pricing the spectrum.) If this spectrum were reallocated efficiently to other spectrum uses and, within those uses, to users who have insufficient spectrum then there could be a welfare gain, but only if the value in the alternative use exceeds that in the existing use. Note that a very small price changes leads to large gains initially as unused spectrum is returned, followed by movement up the spectrum demand curve with further price increases which may or may not involve net benefits depending on the value in alternative uses.

For new services that may occupy spectrum released as a result of AIP the value of surplus under the demand curve between the actual price and price at which demand is zero should be measured.[98] We note that the scale of gains for new services could be large, as the entire area under the demand curve is counted.[99]

11.8.4 Application

Applying the approach just described is by no means straightforward as much of the data required is not available. Below we illustrate the issues for two examples, namely PMR (which illustrates the issues for a marketed service) and defence (which illustrates the issues for a non-marketed service). The key point is that the information on users' willingness to pay for spectrum and the price elasticity of demand for spectrum are required if costs and benefits are to be estimated. The RA has collected information of this kind for some but by no means all uses. We recommend that this data is collected on a more comprehensive basis and is collected regularly for each service, at least every 5 years, given that demand conditions may change over time.

11.8.4.1 PMR

The main potential benefits from applying AIP to PMR use comprise gains from reassignment of spectrum to more efficient users or the ability to accommodate more users in a band (e.g. as might occur if incumbents used more efficient technology or reduced the area their transmissions sterilise). The potential costs are those that could arise if AIP is inappropriately

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[96] Examples of services that might fall into this category could include PMR and fixed links in uncongested locations, paging and FWA.

[97] Note there is no benefit from reassignment between users because there is an excess supply of spectrum.

[98] This approach to estimating the consumer surplus for new services is described in Valuing the Effect of Regulation on new Services in Telecommunications, Jerry Hausman, Brookings Papers: microeconomics 1997.

[99] Hausman's (1997) op cit, results for voice messaging and cellular services are indicative. Similarly Romer (1974) argues that the introduction of new goods made possible by trade liberalisation can yield substantial welfare gains. (New goods, old theory and the welfare costs of trade restrictions, P Romer, *Journal of Development Economics*, 43, 1994).

applied, for example in cases where there is no congestion, or the level of AIP is too high in which case spectrum is returned to the regulator and is left unused.

To assess the potential scale of benefits one ideally requires information on

- the price sensitivity of the existing PMR users, so as to estimate the amount of spectrum that might be released for new users;
- the number and type of users who at present cannot gain access to spectrum in their desired location and band and are having to use a more expensive alternative;
- the relative cost of using PMR versus possible alternatives (e.g. cellular, PAMR), as the additional cost multiplied by the number of PMR users who would switch back to PMR given suitable spectrum could be used as a measure of the benefit from having more PMR spectrum available;
- the consumer/producer gain from replacing low with high value users.

The RA has undertaken research on the demand for PMR services, which includes an estimate of the price sensitivity of demand that could be used to estimate the first effect. The second item is probably not known. The third item could be calculated based on traffic/calling assumptions and market information. The fourth item could be estimated based on information the RA has gathered PMR users' willingness to pay for spectrum disaggregated by type of user.

11.8.4.2 Defence

Outcomes here depend on the impact of changing prices on defence funding. If the Ministry of Defence's (MoD) budget is increased to offset the increase in AIP (as has happened in the past) then there will either be:

- no impact if AIP does not affect behaviour; or
- a positive impact on welfare if the financial gain from reducing AIP provides an incentive for the MoD to release spectrum (perhaps sooner than might otherwise be the case). The size of this gain will depend on the service that will be reallocated the spectrum.

Clearly in this case the key information required concerns the identification of the spectrum that might be released and the potential other users of the spectrum. It would be a matter for the regulator to identify such spectrum and then willingness to pay estimates could be used to estimate its value.

11.9 Summary

This section has addressed a range of implementation issues. In summary we recommend that:

- New values for AIP are implemented with a short if any transition period, following appropriate consultation, particularly if trading is not introduced immediately.
- AIP should be reviewed about every five years and the regulator should commit in advance to a well-defined review process.
- The regulator monitors the impact of pricing and reports evidence on the efficiency benefits achieved. Data that should be collected by the monitoring activity are specified.

- In uncongested locations, users should pay fees or administrative charges that are set at a level that recovers the variable costs incurred by the regulator. It may be expedient to set these charges as a fraction of the AIP but this link should not be perpetuated over time, since this could mean increasing fees when this is not justified on efficiency grounds.
- The regulator undertakes research aimed at producing information on users' willingness to pay for spectrum so that the costs and benefits of AIP can be assessed. The data should be collected on a more comprehensive basis than has been done previously and should be collected regularly, at least every five years, given that demand conditions may change over time.

Glossary

2G	Second generation mobile system
3G	Third generation mobile system
ADSL	Asymmetric Digital Subscriber Lines
AIP	Administered incentive pricing
AM	Amplitude modulation
ATC	Air Traffic Control
ATS	Air Traffic Services
Band III	Frequencies in range 174-230 MHz
BER	Bit error rate
BPSK	Binary phase shift keying
BSS	Broadcast Satellite Service
C band	Frequency band between about 4 and 6 GHz
CAA	Civil Aviation Authority (UK)
CBS	Common Base Station
CEPT	European Conference of Postal and
DAB	Digital Audio Broadcasting
dBW	Decibels relative to one Watt of power.
DCS1800	Digital Cellular System 1800 (former term for GSM services operating at 1800 MHz)
DSL	Digital subscriber line
DVB	Digital video broadcasting
DTI	Department of Trade and Industry
DTV	Digital Television
DVB-T	Digital Video Broadcasting - Terrestrial
E GSM	Extended GSM
EC	European Commission
EIRP	Effective Isotropically Radiated Power
ERC	European Radiocommunications Committee
ERO	European Radiocommunications Office
ETSI	European Telecommunications Standards Institute
EU	European Union
FM	Frequency Modulation
FSS	Fixed Satellite Service
FWA	Fixed Wireless Access
GHz	Gigahertz
GSM	Global System for Mobile Communications Groupe Spécial Mobile. See ERC Decision ERC/DEC/(94)01.
GSM1800	GSM using 1800 MHz frequencies
GSM900	GSM using 900 MHz frequencies
HF	High Frequency (3 to 30 MHz)
ITC	Independent Television Commission
ITU	International Telecommunications Union

ITU RR	ITU Radio Regulations
ITU-R	ITU-Radiocommunications Sector
ITV	Independent Television
JFMG	Joint Frequency Management Group
kHz	kilo Hertz
L band	Frequency band around 1.5 GHz
MASTS	Mobile Assignment Technical System
MHz	Megahertz
MoD	Ministry of Defence
NATO	North Atlantic Treaty Organisation.
NATS	National Air Traffic Service.
OFCOM	Office of Communications
OFTEL	Office of Telecommunications – responsible for regulating the UK telecoms industry
PAMR	Public Access Mobile Radio
PCN	Personal Communication Networks (at 1800 MHz)
PMR	Private Mobile Radio
PMSE	Programme Making and Special Events.
RA	Radiocommunications Agency (UK)
RF	Radio Frequency
RR	Radio Regulations
RSA	Recognised spectrum access
S-DAB	Satellite Digital Audio Broadcasting
SDSL	Symmetric Digital Subscriber Line
STU	Standard Trading Unit (of spectrum)
TETRA	Trans European Trunked Radio System
TETRAPOL	Proprietary Digital Trunked Radio Standard
TV	Television.
UHF	Ultra High Frequency (300 to 3000 MHz)
UMTS	Universal Mobile Telecommunications System
VHF	Very High Frequency (30 to 300 MHz)
VSAT	Very Small Aperture Terminal
VTS	Vessel Traffic System (radar)
WARC/WRC	World Administrative Radio Conference/World Radiocommunications Conference

Annex 1 Terms of Reference

Review the Spectrum Pricing Methodology for Setting Licence Charges under the Wireless Telegraphy Act 1998. Objectives:

1.1 The Radiocommunications Agency (RA, an executive agency of the DTI) requires a study to review the methodology and function of administrative incentive spectrum pricing and setting licence charges. The purpose of the pricing system is to generate incentives that promote the economically efficient use of the radio spectrum. Raising revenue is not a goal of the pricing system. The study should be divided into two parts with objectives of:

- (Phase A) Formulating a set of guiding principles and a theoretical perspective to guide the setting of administrative prices for radio spectrum;
- (Phase B) Making recommendations for how to set licence prices in broad use categories and to calculate their values in representative cases in each major area of radio application.

A1.1 Phase A

1.2 The Government's policy is for all spectrum users to face incentives to use the spectrum as efficiently as possible. The Government currently calculates and applies pricing as one such incentive mechanism for certain spectrum users. The existing method of calculating spectrum prices is based on the "value of the next best alternative" using a method set out in a report by Smith-NERA for the Agency written in 1996. Phase A of the study should advise whether the existing methodology for calculating pricing generates the optimal incentives for licensees to use spectrum efficiently. If not, it should develop a new methodology that is economically robust and can be implemented in practice. The emerging methodology must be flexible enough to adapt to ongoing changes to the institutional and technical environment in which pricing will operate, including but not exclusively:

- the international context which, in most cases, specifies the frequency bands which specific radio application can use;
- the introduction and growth of spectrum trading (which is expected to be introduced in 2003);
- the increasing use of auctions and other market-based methods of assigning spectrum property rights;
- technological change and the increasing opportunities for cohabitation of frequency bands;
- the technical realities of radio engineering (channelisation, rasters, necessary bandwidth, adjacent channel considerations and interference).

1.3 The methodology should be consistent with the best available understanding of microeconomic price theory and radio engineering. In particular, the analysis and recommended method of pricing should concentrate on exposing users to the opportunity cost of their spectrum use in a way that provides effective incentives for efficient use, and in doing so take account of such concepts as second and third best considerations, externalities and indivisibilities.

The contractor need not consider the effect of pricing on competition. The contractor should assume that competition policy is effective.

1.4 In developing the pricing methodology, Phase A should consider the features that might make a particular sector unsuitable for full or partial spectrum pricing. In particular it should develop principles that could be practically applied in identifying those areas of the spectrum that are, and are not, suitable for the application of spectrum pricing as an incentive for efficient spectrum use – for instance where there is no opportunity cost. It should ensure that the methodology is flexible enough to deal with these cases. The methodology should be robust enough and flexible enough to be applicable to all spectrum uses across the whole radio spectrum (9kHz to 300GHz), both now and in the future and should examine at least the following uses of radio:

- Public mobile networks
- Terrestrial Broadcasting
- Private mobile radio
- Fixed links
- Fixed Wireless Access (including the converged local area network technologies)
- Programme Making and Special Events
- Satellite services
- Maritime (communications and radar)
- Aeronautical (communications and radar)
- Amateur radio
- Science Services
- Public services, including defence, police, ambulance and fire services

1.5 The recommended method must:

- provide clear, effective and fair price signals to which users can respond;
- be consistent with the principles of economics and the realities of radio engineering;
- be equally applicable to public sector and private sector users;
- be consistent with the policy encapsulated in section 2 of the Wireless Telegraphy Act 1998 and Ministerial commitments given during passage of that legislation;
- be consistent with latest Government policy as set out in its response to the Independent Review of Spectrum Management, and the Communications Bill; and
- practicable.

1.6 The methodology should also be consistent with RA's spectrum management objectives and duties. RA's primary objective is to promote the optimal use of the radio spectrum. The concept of "optimal use" includes both economic and noneconomic benefits, such as the cultural, scientific and social. In setting fees, RA will be required by law to have regard in particular to the availability of, and present and expected future demand for, spectrum; and to desirability of promoting efficient spectrum management and use, economic and other benefits, innovation and competition.

1.7 Spectrum pricing is at present applied to licences issued under the Wireless Telegraphy Act. The Communications Bill, currently before Parliament, makes provision for a new complementary system of Recognised Spectrum Access. RA published a consultative document on 15 July 2002 about how RSA might be introduced, with particular reference to satellite downlinks. It is a purpose of this study to devise a pricing methodology for RSA, as well as for licences.

1.8 The Government's response to the Independent Review made specific reference to the relevant spectrum management objectives that incentive pricing would be expected to promote in broadcasting. These are, in the case of analogue terrestrial television, to promote switchover and, in the case of digital terrestrial television, to promote more efficient use of the available spectrum. The relevant objectives for sound broadcasting and the extent to which incentive pricing would be appropriate given the constraints imposed by the broadcasting regulatory framework remain to be determined and the study is expected to make recommendations on these questions.

1.9 Finally, Phase A will be expected to recommend a list of spectrum uses (between 10 – 20 uses) to be used in Phase B to demonstrate what the illustrative charges would be under the new administrative pricing methodology.

A1.2 Phase B

1.10 Prior to its initiation, Phase B of the study should agree with the RA the list of spectrum uses to be used to demonstrate the practical application of the method constructed in Phase A. In conducting Phase B, the study should pay particular attention to ensuring that, so far as possible, the incentives facing users are clear, effective and are consistent between the public and private sectors.

1.11 For any given methodology the study should provide evidence to support its calculation of recommended prices. For instance, for each spectrum application the study should identify the core attributes of the application and define the associated spectrum demand before applying the methodologies identified in Phase A. Also, for instance, if a 'next best alternative' approach to calculating opportunity cost is being applied, then for each application identified, the study should (where possible) indicate a range of next best alternative spectrum applications and demonstrate what is the next best alternative in terms of the attributes and spectrum demand of the spectrum application. The study should also demonstrate how the opportunity cost can be measured for any given spectrum use and those identified for the alternative uses. If the "next best alternative approach" is not valid, the contractor should demonstrate what alternative option should be used.

1.12 The study should also identify any technical, regulatory, or other factors that would effect the successful implementation of the methodology.

1.13 In all instances the study will provide calculations of spectrum prices in all major uses where spectrum pricing is considered to be applicable.

Annex 2 Case for Applying AIP by Service

A2.1 Aeronautical

A2.1.1 Communications

The international status of the aeronautical communications bands means that they cannot be deployed for another use. However, bands used for aeronautical communications are heavily used and demand is growing, particularly in the commercial aviation sector. To address congestion in the 118-137 MHz band, which is used to control traffic on civil aviation routes, narrower channel spacings have been introduced and in time digital voice and data systems will replace existing analogue systems. In 2001 the CAA adopted a requirement that all aircraft flying above 24,500 feet (in practice all commercial aircraft) must be equipped with narrowband radios,[100] however, NATS has not yet implemented narrowband transmissions due to cost constraints. The CAA would like to reduce the altitude threshold further but this may mean general aviation aircraft would have to re-equip with narrowband radios. This may hinder the longer term adoption of digital technology, since there is an understanding between the CAA and general aviation community that only a single technology shift (i.e. a move from analogue to digital without an interim move to narrowband) would apply. However, since the adoption of digital technology will require international agreement and extensive preplanning of the frequency band it is unlikely to adopted for many years.

At present neither NATS nor general aviation users[101] appear to have a financial incentive to move to narrowband communications. Spectrum pricing could provide this incentive and thereby help relieve congestion and delay the need to look for other bands to support aeronautical communications.[102] It could also lead to a more efficient assignment of spectrum between low and high value users. We note that the Independent Spectrum Review also concluded there would be benefits from pricing to encourage migration by on-board aeronautical systems to more spectrally efficient radio equipment.

A2.1.2 Radar and Radio-navigation systems

Many radio-navigation and radiolocation (radar) bands are internationally designated for specific systems (e.g. Instrument Landing Systems, radio altimeters, etc) and would therefore not be suitable for change of use. However, there are a number of bands used for these applications in the UK that are not constrained in this way, and where AIP could in principle be applied. The best example is channel 36 in the UHF TV band, which is used exclusively in the UK by aeronautical radars while the rest of Europe uses it for broadcasting.

Where radars operate in internationally designated bands, a distinction should be made between primary and secondary radars. Primary radars rely on the passive reflection of the transmitted signal, whereas secondary radars rely on a re-transmitted version of the transmitted signal, typically from a transponder located in an aircraft. This raises two key issues which could affect the approach to pricing radar spectrum, namely:

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[100] In practice aircraft have dual mode radios that can operate in either narrow (8.33 kHz) or standard (25 kHz) spacings. Aircraft that have no narrowband capability must fly below 24,500 feet which causes additional fuel consumption and engine wear and tear.

[101] Commercial aviation communication over 24,500 feet uses only six channels in the band while the remainder (i.e. the majority) are used by general aviation and/or at lower altitudes.

[102] There is a WRC 2007 agenda item to identify additional spectrum for aeronautical mobile communications, possibly by converting existing radio-navigation spectrum to mobile or shared use.

- Power: primary radars must generate much higher powers to enable detection of the reflected signal, and are hence much more likely to generate interference to other users.
- Feasibility of change: Because secondary radars rely on transponders which must be deployed in large quantities (e.g. on every commercial or military aircraft) it would be far less practical to implement changes that might lead to improved efficiency.

A report recently commissioned by the RA[103] observed that the latest generation of radars based on solid-state pulse-compression technology provide significant improvements in spectrum efficiency compared to older magnetron-based systems. The main benefit is likely to be a reduction in the level of out of band and spurious emissions generated by high power primary radars, reducing the impact such radars can have on services in adjacent bands, rather than a significant reduction in the operational bandwidth of the radar (newer radars often employ frequency agility which improves performance but requires more bandwidth).

Hence the application of AIP to radars may need to take account of the opportunity cost arising not only from the denial of spectrum in the band the radar operates in but also in adjacent bands. This is a significant point, since the operational radar band will often be an exclusive international allocation with effectively a zero opportunity cost, whereas the out of band interference generated by older radar equipment could affect the operation of other services (e.g. fixed links) in adjacent bands. Hence the pricing of spectrum for high power primary radars may need to take into account the potential impact on adjacent band services, in which case newer radars complying with the latest ITU out of band emission limits would merit lower fees than older, non-compliant radars.[104]

As noted above, some of the spectrum currently used by aeronautical radars or radio-navigation systems in the UK could be used by alternative uses, for example:

- TV Channel 36 could be used for TV services as it is elsewhere in Europe
- At 1350 – 1365 MHz where fixed links could potentially make more use of the band (although we understand the RA does not currently consider there to be any significant constraint on fixed links in this band)
- 2.7-2.9 GHz band is being considered internationally for potential longer term shared use with mobile services, however, this not likely to be implemented before 2010.[105]

AIP could be applied to this spectrum, unlike bands that are exclusively allocated on an international basis. Although we suggest that for the 2.7-2.9 GHz band the RA should wait until the designation of the band is more certain before applying spectrum pricing.

In principle therefore there is a case for applying AIP to aeronautical radar services in bands which could potentially be used by other services facing problems of spectrum congestion, or to older systems whose emission characteristics have the potential to significantly constrain the use of adjacent bands by other services.

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[103] Report of an Investigation into the Characteristics, Operation and Protection Requirements of Civil Aeronautical and Civil Maritime Radar Systems, October 2002

[104] An ITU-R Recommendation and an ETSI standard are being drawn up to enable mandatory limits to be applied to new equipment.

[105] Although the results of compatibility studies are not promising and we understand demand for aeronautical services in the band are increasing due to growing pressure on the 1.3 GHz band.

A2.2 Broadcasting

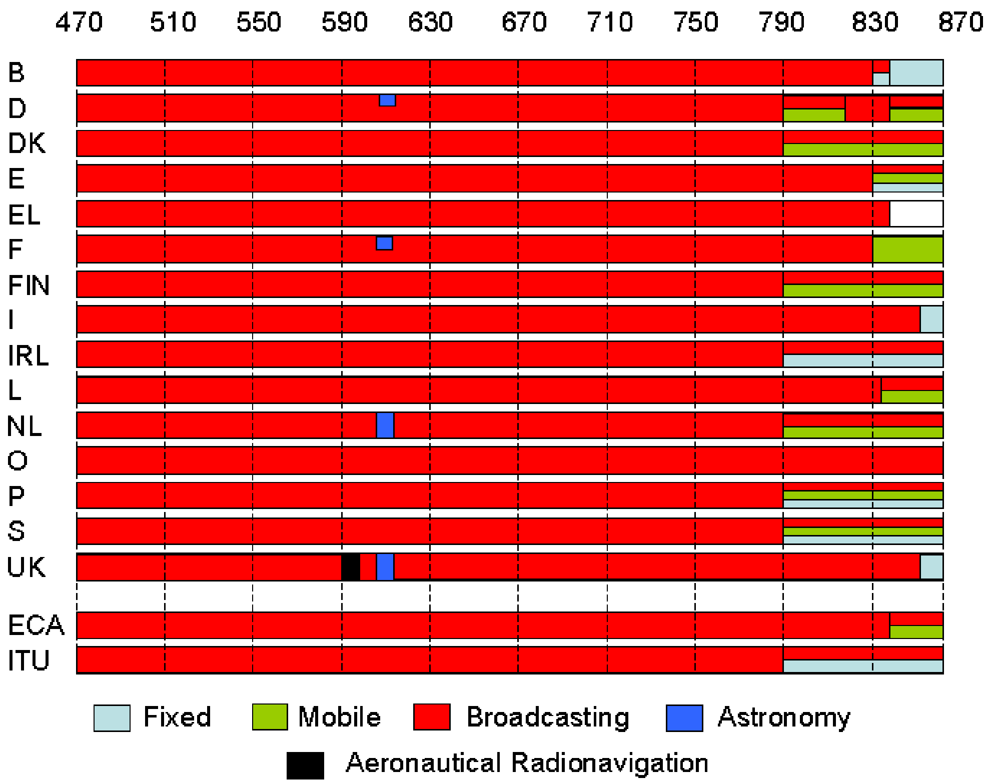
A2.2.1 Television

The Government Response to the Independent Spectrum Review endorsed the application of spectrum pricing to broadcasters to promote efficient spectrum (para 8.12), taking account of the wider public policy context (e.g. broadcasters' PSB obligations). The Government also gave a commitment that charging for analogue spectrum will not start before 2006 at the earliest and that charging for digital TV licensees will not start before 2010.

Spectrum used by TV broadcasters could be used by other uses and there is potential excess demand for the spectrum from other broadcasters. Figure A2.1 shows that in Europe the upper end of the UHF TV band is currently widely used by fixed and mobile services. The band above 806 MHz has also been identified by the ITU as potential future expansion spectrum for 3G mobile services. In future, after switchover other new mobile services could use the spectrum although this would require a change in the ITU radio regulations and would need to be accommodated by the new TV spectrum plan being development in Europe over the next 2-3 years. Assuming these changes occur then there is a case for pricing the UHF TV spectrum.

Although the existing public service broadcasters are constrained in the way they use the analogue spectrum by the Stockholm Plan, environmental constraints on sites that may be used for high-powered transmitters and coverage obligations, pricing could help promote switchover so long as prices are set appropriately. In the case of digital services, many investment and frequency planning decisions have still to be made and service constraints are likely to be less severe. Hence pricing (or even its prospect) has the potential to modify broadcasters' behaviour and so should be applied.

Figure A2.1 Use of UHF TV bands in Europe



A2.2.2 Sound Broadcasting

Sound broadcasters currently pay cost based charges for their spectrum. There is excess demand for FM spectrum, though demand is weaker for digital spectrum and AM frequencies.[106] Whether incentive pricing would be appropriate depends on the likely impact on the behaviour of sound broadcasters and/or whether the spectrum could be used by other uses and users.

A2.2.2.1 Analogue spectrum

Local radio commercial broadcasters' use of analogue spectrum is constrained by the spectrum plan devised by the Radio Authority. This determines the location and coverage of services and technical parameters of transmissions (e.g. power).[107] Pricing cannot directly affect this spectrum use. The Radio Authority must first relax the regulations before changes can be possible e.g. by allowing broadcasting in mono rather than stereo which would significantly increase channel re-use and hence the available spectrum for radio services in high demand areas. Pricing can, however, affect users' incentives to seek changes to the regulations and indicates their opportunity cost to regulators and government.

National commercial radio operators have minimum coverage requirements and discretion as to how far they go beyond these. Pricing could therefore be used to ration demand for this additional spectrum, however, it should be noted that the frequencies used are likely to be in areas of low population density and so low demand.

BBC services do not have the same formal licensing and coverage requirements as commercial radio, but there could be policy constraints on any significant changes in the coverage and/or the number of services provided. Again pricing could be helpful in indicating the opportunity cost of these constraints.

Potential alternative uses of the FM spectrum are very limited since the band is allocated globally to sound broadcasting and hence no equipment is available to cater for alternatives. The only practical alternative uses for the foreseeable future are likely to involve deployment of FM broadcast technology for uses such as provision of localised "tour guides" or for PMSE (e.g. wireless microphones). Any more radical change of use would probably require international agreement and would be difficult to implement in practice, since the widespread availability of low cost transmission equipment would probably result in widespread illegal use (by pirate radio stations) if the band was vacated by existing broadcasters.

In the case of the AM spectrum, developments are underway internationally to introduce digital technology which could overcome the quality deficiencies of AM broadcasts and potentially stimulate more demand for this spectrum. Otherwise the only practical alternative uses are similar to those identified above for FM.

None of the alternative uses of the FM and AM spectrum seems practical in the next ten years[108] and so this does not give a compelling argument for pricing analogue spectrum used by radio services, unless a significant demand for digital AM services arises. Rather the argument for pricing the analogue spectrum derives from the excess demand for radio licences. In the case of commercial services, pricing could be applied once the current

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[106] The Radio Authority plans to undertake a consultation on demand for AM spectrum.

[107] The spectrum plan for analogue services can only be changed once the current 12 year analogue licences expire.

[108] Not least because the value of spectrum in the alternative uses is likely to be less than that for sound broadcasting.

licences have expired and its application could provide incentives to relax technical regulatory constraints. Pricing could be applied much sooner to the BBC services, say after the Charter Review, and again could provide incentives to relax any policy or technical constraints on the provision of services.

A2.2.2.2 Digital spectrum

In the case of spectrum used for digital radio services at 217.5- 230 MHz (Band III), the Radio Authority determines technical aspects of licences including spectrum use, although users could have some flexibility to reduce the area they sterilise (but not the population covered) by replacing a small number of high powered transmitters with a larger number of smaller targeted transmitters. Pricing could give incentives for this kind of behaviour. In addition, policy factors could be much less of a constraint on the coverage of the BBC's services given the current low service take-up.

There could be much greater flexibility in new spectrum made available for DAB at L band and auctions and/or pricing might be feasible. In this band there is the possibility of general multiplexes which will not be subject to the regulatory constraints that apply to the existing multiplex operators. This would allow greater efficiency benefits to be derived from applying AIP.

Alternative uses of DAB spectrum include PMR or PAMR in Band III and satellite DAB in L Band.

A2.3 Defence

This study concurs with the finding of previous studies that defence use of spectrum in bands that could potentially be used by civil services facing congestion (e.g. fixed links, PMR, PAMR, cellular services) should be priced.

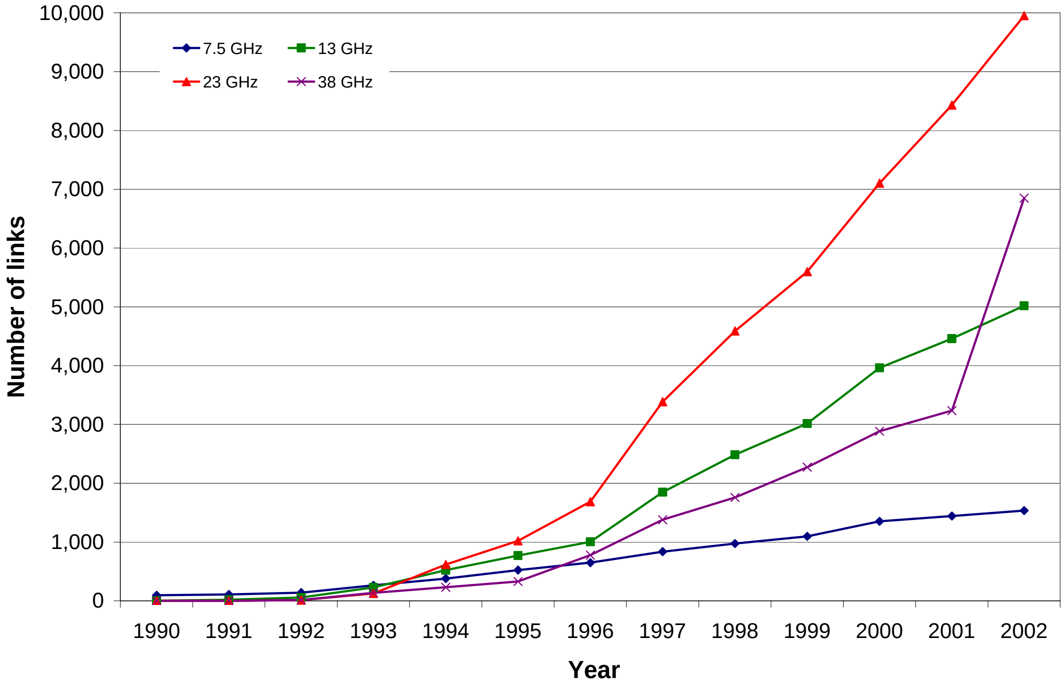
NATO bands should be excluded from consideration because these bands could not be reallocated to other services (for policy reasons) and so there is a zero opportunity cost to defence use (in terms of displacing use by other potential users of those bands). However the same considerations noted above with regard to out-of-band emissions from high power primary radars also apply to such systems operating in military bands and pricing may be appropriate where the potential for harmful interference to adjacent band systems is identified.

A2.4 Fixed services

A2.4.1 Fixed links

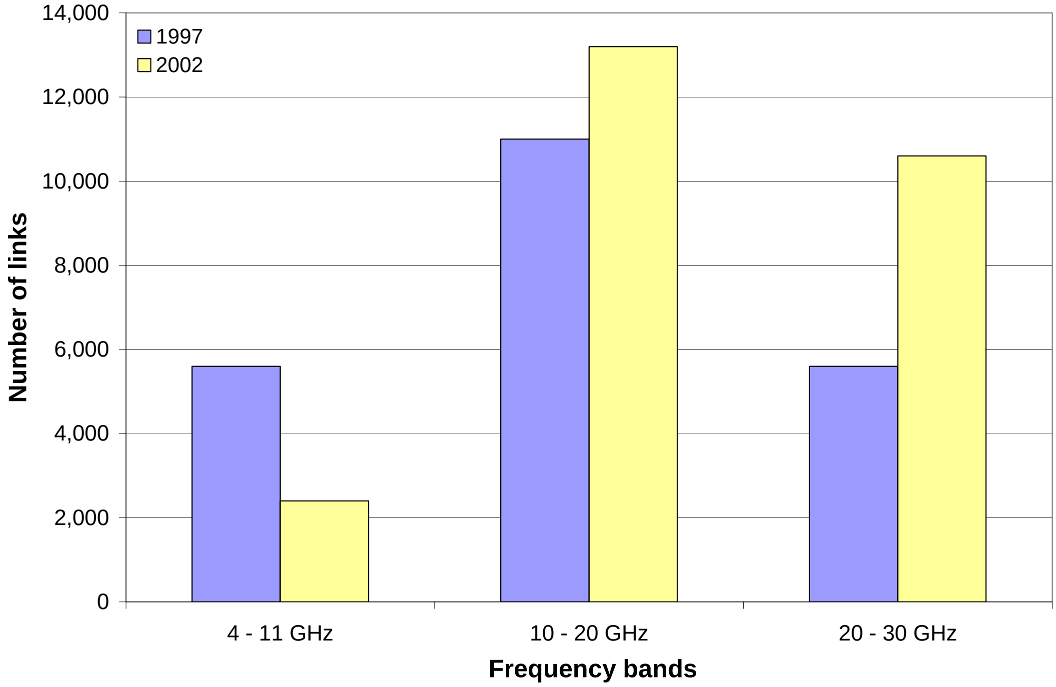
Fixed link spectrum up to 15 GHz is currently subject to AIP in areas of high demand. The cut-off at 15 GHz was based on analysis of the extent of congestion in fixed link bands in 1997. Since then demand for fixed link spectrum in higher frequency bands (i.e. in the 23, 26 and 38 GHz) has grown at a substantially faster pace than in lower frequency bands. The frequency bands are used primarily for infrastructure links for mobile networks and for customer access links. Despite this growth significant congestion problems have not yet been experienced, except in some city centres. This reflects the greater re-use capability of these bands. However congestion is likely to arise at 23 GHz in particular if the current high growth rates continue (see Figure A2.2). Further capacity for very short fixed infrastructure and access links will in future be provided in bands at 55, and 65 GHz (the 58 GHz band is also available for licence-exempt, non-protected links).

Figure A2.2 Fixed link assignments in RA-managed bands, 1990 - 2002



In bands below 13GHz demand has declined when account is taken of the bands formerly allocated exclusively to BT (i.e. 4, 6 and 11 GHz) (see Figure A2.3). Nevertheless, there continues to be congestion at the main nodes in trunk networks and/or in bands that are shared with satellite services.

Figure A2.3 UK fixed link assignments in 1997 and 2002, by frequency range (source: CEPT)



AIP should therefore continue to be applied to fixed link bands below 15 GHz and there may be a case for extending pricing to higher bands, notably 23 GHz. Note these conclusions apply to both private and public sector users of the bands, as all users have options to economise on their spectrum use.

A2.4.2 Fixed Wireless Access

FWA bands could potentially be used by other services, such as fixed links, satellite services and PMSE. In the longer term there could be excess demand for the spectrum from FWA services. FWA services are therefore a potential candidate for AIP.

Spectrum for FWA services is currently auctioned in which case there is no role for AIP, however there is one existing operator which was licensed on a first-come, first- served basis (Firstnet) and the possibility of using means other than auctions to license remaining 10 and 28 GHz spectrum has been mooted recently by the RA. It is assumed that this would only apply in the event that an auction attracted insufficient bidders in which case AIP should only be applied if there is demand for the spectrum from other uses, say, fixed links.

A2.4.3 Scanning Telemetry

This service uses a block of 2 x 1 MHz spectrum in the 450-470 MHz band which could alternatively be used by PMR and PAMR services (including TETRA) but is currently subject to re-planning along with the rest of this band. Users have the potential to use alternative technologies such as TETRA or TDMA following re-planning, and in some cases (but not all due to inadequate geographic coverage) may be able to make use of public data networks. Users can also use wire lines in locations where these are available. In view of the excess demand for this spectrum from other uses, use of spectrum by scanning telemetry should be subject to AIP.

A2.5 Maritime services

A2.5.1 Communications services

The situation for maritime services is similar to that for aeronautical services, in the sense that communications uses are heavily constrained by the international status and use of the bands and the fact the spectrum is largely used for safety purposes. However, maritime business radio, which allows businesses to communicate with ship stations from coastal stations, is a UK only allocation which uses bands shared with PMR. In this instance AIP should be applied as the opportunity cost of the spectrum is non-zero and users could potentially modify their spectrum demand by using more spectrally efficient equipment or in some cases switching to public networks.

A2.5.2 Radar and Radio-navigation systems

The comments made above concerning aeronautical primary radar also apply in the maritime case and so there may be a case for applying AIP to these services in circumstances where there is a possibility of constraints on other uses including those in adjacent bands.

A2.6 Programme making and special events

There is growing demand for spectrum for programme making and special events (PMSE) and furthermore many of the frequencies used for these services could be used by alternative uses such as TV broadcasting and fixed links. The opportunity cost of spectrum used by these services is therefore positive and congestion remains despite the application of AIP to date. PMSE users can economise on their use of spectrum by either adopting more efficient digital technology or by moving to bands that are not congested. Hence spectrum pricing should be applied to PMSE services. In doing this it may be necessary to be mindful of the possibility that high prices could result in an increase in illegal use of spectrum. While this enforcement issue arises in all spectrum categories, the setting of AIP may amplify non-compliance and require the RA to devote more resources to enforcement activities.

A2.7 Private mobile radio

Demand for PMR spectrum remains high. The number of licenses issued for wide area systems has fallen by 5-7% over the last two years, however, there is continuing growth in on-site systems and there is still congestion in some areas, particularly in London (in the sense that it is not possible to make additional assignments in some bands). PMR users can in theory economise on their use of spectrum by switching to narrowband systems (although the lack of a competitive equipment market appears to have prevented this option being taken up to date), reducing the coverage area of their systems (though unless they switch from a wide area to an on-site licence this does not currently affect the fee) or switching to public communications networks. Digital standards are being developed and there is interest from some users in using either the TETRA or Tetrapol standard for PMR, although currently there is no spectrum available for this use. For on-site users there is also the option of using licence exempt spectrum allocated to PMR446.

Spectrum pricing should therefore continue to apply to PMR. This conclusion applies to both private and public sector users (including public safety services), with the possible exception of the NATO band used by the Airwave TETRA networks, since the use of this band by commercial services is constrained by the international agreement between NATO and CEPT.

A2.8 Public mobile networks

Services to be considered here include second and third generation cellular, public access mobile radio (PAMR), mobile data, paging and common base stations (CBS).

Pricing has been applied to all of these services, except where licences have been auctioned (i.e. third generation services). In the case of cellular and PAMR congestion remains in the sense that there is demand for additional spectrum. Additional spectrum has been allocated to cellular services in the 3G expansion bands and there is the potential to make more spectrum available for PAMR in band III and the UHF PMR bands, particularly when the public safety users migrate to TETRA in the 380 – 400 MHz band and the replanning of the 450 – 470 MHz band is complete. There is also the possibility that GSM or CDMA services could be introduced in the latter band, depending upon international market developments. Pricing should continue to be applied in congested spectrum and any new spectrum released for these services unless of course the latter is auctioned.

By contrast, demand for mobile data, paging and CBS services has been in decline primarily because users have switched to use of cellular services. The spectrum used by these services could however be used by either PAMR or PMR services (and potentially cellular in the 450 – 470 MHz band post-replanning) and so the opportunity cost of the spectrum used is non-zero. Pricing should therefore continue to be applied.

A2.9 Satellite services

AIP is currently applied to permanent and transportable earth stations and VSATs in exclusive and shared satellite bands. The Independent Spectrum Review suggested that AIP only be applied in shared bands as the opportunity cost of spectrum in exclusive bands is zero. The reason for this is that international agreements constrain the potential use of these bands and within the bands the availability of orbital slots and spectrum is the constraint on use. One possible exception is the mobile satellite service at L Band where both orbital slots and spectrum constrain the number of operators that may use the band.

In exclusive satellite bands links are co-ordinated at a satellite network level through ITU processes and once this co-ordination has occurred there is no further constraint on use. Congestion of orbital slots may occur however and the ITU is putting in place procedures to improve rationing of demand for slots although it is not yet known how effective these will be. Auctions might be used to assign orbital slots allotted to national governments. It might be argued that AIP could give long-term incentives to invest in more spectrally efficient satellite technology in exclusive bands. However, once transmissions are digital (as most of them are now) there is little further that can be done to enhance the efficiency of either the transponders or the earth stations. In addition, the separation between satellites – typically 2 or 3 degrees – is largely determined by the nature of the applications seeking to use the spectrum, as closer separation implies the need for larger terminals. The trend in market demand for satellite services is for smaller satellite terminals and so greater rather than smaller separation. There would not appear to be a role for administered incentive pricing to promote more efficient spectrum use, given that a change of allocated use for the bands is not feasible (because they are allocated internationally on an exclusive basis).

The situation is different in shared bands where downlinks and uplinks may constrain terrestrial use of spectrum, in which case spectrum pricing would have a role to play in encouraging economically efficient sharing of the spectrum where congestion occurs. Satellite users have opportunities to economise on their spectrum, e.g. through better protection of antennas/dishes, changing the location of their systems or using terrestrial communications systems. Hence pricing should continue to apply in shared bands where there is excess demand from alternative uses of the spectrum.

Some satellite uses in shared bands involve only space to earth transmissions and so cannot be licensed in the UK. These uses are potential candidates for RSA, however, there is a potential "free rider" problem. If one satellite operator pays AIP under an RSA which allows transmissions across the whole country in a given frequency band, then a second satellite operator could transmit on the same frequencies from a satellite at a different orbital location without causing any interference. Furthermore the second operator gains protection from interference under the first operator's RSA.

A2.10 Science services

The main services in this category are radio astronomy, earth exploration services and meteorological uses (meteorological aids, wind profile radars). The meteorological service is part of the Ministry of Defence and so its use of spectrum is in military bands. The conclusions given above for defence therefore apply.

A2.10.1 Radio Astronomy

Radio astronomy services do not transmit radio signals but rather need protection from interference from other services so that cosmic emissions can be observed. This means there is potentially an opportunity cost to use of spectrum by radio astronomy, particularly where the band is not exclusively allocated to astronomy on a global basis. Radio astronomy users have a number of options for economising on their use of spectrum including protecting their radio telescopes and or relocating them to uncongested locations. Spectrum pricing should therefore be applied in bands that are not globally reserved for passive applications. As passive services, these are candidates for RSA rather than licensing.

It has been agreed between the RA and the Particle Physics and Astronomy Research Council that radio astronomy services will pay AIP under recognised spectrum access. The AIP is to be set on the basis of the opportunity cost of the spectrum where this is the value of the spectrum to the use that is denied spectrum access. AIP is to be applied in those bands that are already congested.

A2.10.2 Earth Exploration Services

This involves the use of satellites for climatic and related monitoring. Most bands are exclusive or are shared with other science services. As discussed above, the opportunity cost of spectrum in exclusive satellite bands is zero and so these bands should not be subject to AIP. Where bands are not internationally and exclusively allocated to science services, the arguments given above for radio astronomy apply, and so AIP should be implemented.

Annex 3 Fixed Links

A3.1 Introduction

We have considered a number of potential alternatives to the use of fixed links radio spectrum, namely:

- use of more spectrum-efficient technology within the same frequency band, allowing less spectrum to be used to convey the same amount of data
- use of a higher frequency band where there is greater capacity and less likelihood of congestion arising
- use of a non-radio alternative, e.g. leased line or fibre.

Each of these options is assessed briefly below: it will be seen that option (i) is the lowest cost alternative for a typical link user.

A3.2 Alternatives to use of additional fixed link spectrum

A3.2.1 Use of more spectrally efficient fixed link technology

For most fixed link applications, there is more than one technology option, in terms of modulation scheme. In general, higher level modulation schemes result in a lower spectrum utilisation per unit of data conveyed by the link. For each identified link type (defined by transmitted data rate), we have considered the two most feasible technology options and compared the relative costs associated with each of these options. We have then determined the effective change in spectrum utilisation corresponding to the change in technology and based the marginal value of the spectrum on the cost of the spectral efficiency improvement per MHz reduction in spectrum utilisation per link.

Typically, a reduction of 50% in the required RF bandwidth to convey a given data transmission rate can be achieved by adopting the next higher level (more efficient) modulation scheme. However, this reduction in bandwidth required does not equate to a 50% reduction in spectrum utilisation. The reduction in spectrum utilisation is less than this because the more bandwidth-efficient equipment is more susceptible to interference and therefore needs greater separation from other co-channel links. Work carried out internally by the RA suggests that when this reduction in channel re-use capability is taken into account, the actual spectrum requirement for the more bandwidth efficient links is around 75% of that required for the less efficient links.

Generic fixed link costs have been identified from the “Guide to Fixed Terrestrial Systems Cost Modelling”, developed for the Agency by Ovum and Aegis,[109] and from the Long Run Incremental Cost (LRIC) model for GSM cellular networks, developed for Oftel by Analysys. The Ovum / Aegis model identifies base line costs for radio links using QPSK modulation, for three specific data rates (2, 34 and 155 Mbit/s). A premium relative to this base cost is then identified for various other modulation types (16QAM, 64QAM, etc), each of which affords a degree of improvement in overall spectrum efficiency. The Analysys model provides cost estimates for 2, 8, 16/17 and 32/34 Mbit/s links. Table A3.1 indicates the estimated capital

[109] Cost assumptions are understood to be based on typical price levels, determined by discussion with equipment vendors

investment costs for radio equipment per link for various combinations of link data rate and modulation scheme:

Table A3.1 Typical capital costs for various types of fixed link equipment

Data rate:	2 Mbit/s	4 Mbit/s**	8 Mbit/s*	17 Mbit/s*	34 Mbit/s	155 Mbit/s
QPSK mod	£5,000	£5,750	£6,500	£8,150	£10,000	£16,000
16QAM mod	£8,000	£9,200	£10,400	£13,040	£16,000	£25,600
128QAM mod	n/a	n/a	n/a	n/a	n/a	£28,800

*based on incremental cost relative to 2 Mbit/s link, from Oftel LRIC model for cellular networks.

**estimated by interpolation

Since there is not a linear relation between equipment cost and data rate, the marginal value for individual link types will vary according to which link types are being considered. Each band contains a mix of link data rates, but to ensure technological neutrality a single marginal value should be used for fixed link spectrum. We have therefore determined a value for fixed link spectrum based on a weighted average of the differential costs associated with the use of a less efficient and more efficient modulation scheme for each link data rate, relative to the change in spectrum utilisation. For each link type, we have assumed that two modulation schemes are available and that the more efficient alternative utilises 75% of the spectrum utilised by the less efficient alternative.

The annualised value assumes a real discount rate of 10 % over 15 years and that maintenance costs for the more efficient equipment are the same in absolute terms as for the less efficient equipment (i.e. there is no increase in maintenance costs as a result of choosing the more efficient equipment).

Table A3.2 Marginal values for various fixed link types based on adoption of more efficient link technology

Link Type & less efficient alternative	More efficient option	Spectrum Utilisation (MHz)		Equipment Cost (£)		Value per 2x1 MHz (£)	Annualised value (£ per 2x1 MHz)
		Old	New*	Old	New		
2 Mbit/s QPSK	16QAM	3.5 MHz	2.625 MHz	5,000	8,000	3,429	410
4 Mbit/s QPSK	16QAM	3.5 MHz	2.625 MHz	5,750	9,200	3,943	471
8 Mbit/s QPSK	16QAM	7 MHz	5.25 MHz	6,500	10,400	2,228	266
17 Mbit/s QSPK	16QAM	14 MHz	10.5 MHz	8,150	13,040	1,397	167
34 Mbit/s QPSK	16QAM	28 MHz	21 MHz	10,000	16,000	857	102
155 Mbit/s 16QAM	128QAM	56 MHz	42 MHz	25,600	28,800	229	27

*Note that this value represents the effective spectrum utilisation taking account of the bandwidth reduction (generally 50%) and the reduction in channel re-use capability. Based on work carried out by the RA, we have assumed that the combined effect of these factors is to reduce the spectrum utilisation by 25%.

It is clear from Table A3.2 that the cost associated with upgrading narrower bandwidth links is substantially greater on a per-MHz basis than for wider bandwidth links. However since such links consume a relatively small amount of spectrum, simply averaging the above figures would tend to distort the overall value of the spectrum. We have therefore determined an overall value by determining a weighted average of the above cost per MHz values, based on the total amount of spectrum consumed by each type of link.

Table A3.3 determines the weighted average annualised cost, based on the number of links of each data rate currently licensed by the Agency.

Table A3.3 Determination of weighted average marginal value for fixed link spectrum based on adoption of more efficient link technology

Data rate	Link bandwidth	No of links	Total bandwidth	Value per MHz (£ p.a.)	Total value (£M p.a.)
2 Mbit/s	3.5 MHz	1,086	3,801	410	1.56
4 Mbit/s	3.5 MHz	4,789	16,761	471	7.89
8 Mbit/s	7 MHz	10,454	73,187	266	19.47
17 Mbit/s	14 MHz	2,207	30,898	167	5.16
34 Mbit/s	28 MHz	8,125	227,500	102	23.20
155 Mbit/s	56 MHz	1,812	101,472	27	2.74
Total			453,619		60.02

The weighted average value is thus £60.02M / 453,619 = **£132 per annum per link.**

A3.2.2 Use of a higher frequency band

The use of a higher frequency band will typically involve a doubling of the equipment costs plus additional costs associated with acquisition and rental of the additional site. The latter are assumed to be comparable to the macrocell site costs specified in the Oftel Long Run Incremental Cost model for cellular networks, which defines the costs as follows:

- Initial cost (acquisition, preparation etc): £25,000
- Annual cost (lease etc): £6,000

Equipment costs are assumed to be consistent with those in the RA's own Fixed Link cost model, as referred to in the previous section. The annualised spectrum value based on this option has been determined as follows, assuming a discount rate of 10% and an annual equipment maintenance cost of 12% of capital:

Table A3.4 Marginal values for fixed link spectrum based on migration to higher band

Link Type	Bandwidth (MHz)	Site costs (£)		Equipment Cost (£)		Total Annualised cost (£)	Cost per 2 x 1 MHz (£)
		Initial	Annual	Capital	Maintenance		
2 Mbit/s QPSK	3.5 MHz	25000	6000	5,000	600	10,185	2,910
4 Mbit/s QPSK	3.5 MHz	25000	6000	5,750	690	10,365	2,961
8 Mbit/s QPSK	7 MHz	25000	6000	6,500	780	10,545	1,506
17 Mbit/s QSPK	14 MHz	25000	6000	8,150	978	10,940	781
34 Mbit/s QPSK	28 MHz	25000	6000	10,000	1,200	11,383	407
155 Mbit/s 16QAM	56 MHz	25000	6000	25,600	3,072	15,120	270

Note that the above figures are significantly higher than those obtained by assuming adoption of a more efficient technology (see Table A3.4), reflecting the high costs associated with the acquisition and leasing of additional transmission sites.

A3.2.3 Deployment of a non-radio alternative (leased line)

Deployment of a leased line may be a viable option at some locations (though not all). Typical leased line costs have been determined from the current BT price list and are as follows:

- 2 Mbit/s Megastream link:
- £3,500 connection = £418 p.a.
- Rental: £5,950 + £310 /km = £9,050 for typical 10 km link outside London
- Total annual cost = £418 + £9,050 = £9,468 = £2,705 per 2 x 1 MHz (assuming 2 x 3.5 MHz required for an equivalent radio link)
- 34 Mbit/s Megastream link:
- £9,000 connection = £1,076 p.a.
- Rental: £64,880 + £720/km = £72,080 for typical 10 km link outside London
- Total annual cost = £72,080 + £1,076 = £73,156 = £2,612 per 2 x 1 MHz (assuming 2 x 28 MHz required for an equivalent radio link)

Once again it can be seen that the cost per MHz is very much higher than for the more efficient technology alternative.

For narrower bandwidth links, such as those typically deployed in the 1.4 GHz band, leased lines may be a lower cost option than radio links, because of the relatively high level of the site costs, which are substantially independent of the link bandwidth. This may result in a negative valuation for the radio spectrum (since the cost of using the spectrum would be greater than the cost of a leased line alternative. In such cases it is assumed that users will opt for leased lines where these are available and that radio links will be used at other locations.

A3.3 Conclusion

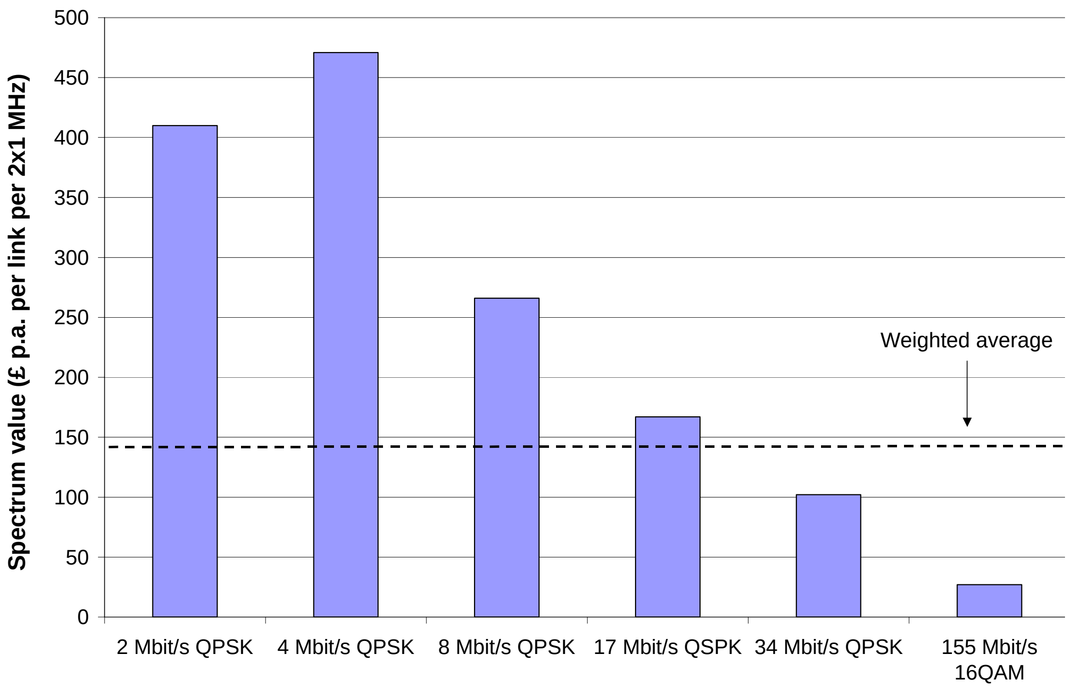
The annualised spectrum value per 2 x 1 MHz based on the three options considered for various link types is summarised below:

Table A3.5 Comparison of marginal values determined by different methods

Link Type	Option (i)	Option (ii)	Option (iii)
2 Mbit/s	410	2,910	£2,705
4 Mbit/s	471	2,961	-
8 Mbit/s	266	1,506	-
17 Mbit/s	167	781	-
34 Mbit/s	102	407	£2,612
140/155 Mbit/s	27	270	-

We therefore conclude that the lowest cost alternative for the typical fixed link user is the deployment of more spectrally efficient fixed link technology as outlined in Section 2.1. The values thus derived depend upon the link capacity (data rate) and are presented in Figure A3.1.

Figure A3.1 Comparison of marginal values for various fixed link types and weighted average



Annex 4 FWA

A4.1 Introduction

In practice it is difficult to define a single marginal value for FWA spectrum as there are so many different possible implementations of FWA networks (e.g. point to multipoint versus mesh networks, different contention ratios, frequency division or time division duplexing) which would result in widely differing values. We have however by way of example attempted to estimate a marginal value for a hypothetical application of FWA spectrum by considering the alternative of using wholesale DSL (for bands up to 10 GHz) or leased lines (for 28 GHz) to deliver an equivalent services

A4.2 Cost comparison based on consumer ADSL: bands up to 10 GHz

FWA System Assumptions:

- Base station bandwidth per sector: 2 x 1.75 MHz
- Total spectrum assigned to base station: 2 x 7 MHz (4 sectors each using 2 x 1.75 MHz)
- Modulation scheme: 16QAM
- Available bit rate per sector (cumulative): 2 Mbit/s (2048 kbit/s)
- Nominal data rate to customer: 512 kbit/s @ 40:1 contention
- No. of subscribers per sector (capacity): (2048/512)*40 = 160

Cost of using wholesale DSL alternative:

- Cost per wholesale DSL: £14.75 / month[110]
- Customer equipment cost = £100 = £26.80 p.a. (10% discount rate over 10 years and maintenance assumed to be 12% of capital)
- Total cost of wholesale DSL for 160 customers: (14.75*12*160)+(26.80x160) = £32,608 p.a.

Cost of deploying FWA:

- £600 per subscriber for customer premises equipment (Aegis estimate)[111]
- £100 per subscriber for base station equipment (Aegis estimate)
- Site acquisition: £25,000 per site = £6,250 per sector (4 sectors per site assumed) = £925 per annum
- Site rental: £6,000 per site = £1,500 per sector
- Total cost of equipment £600 (base station + CPE cost per customer) x 160 (no. of customers) = £96,000

[110] Source: Oftel International benchmarking study of Internet access (dial-up and broadband) - 6 December 2002

[111] Estimates reflect the typical price indicated by equipment vendors for supply and installation of equipment based on quantity production of CPE terminals (1000+).

- Equivalent annual cost of equipment = £25,723 (10% discount rate over 10 years and maintenance assumed to be 12% of capital)
- Total annual cost = £25,723 (equipment) + £925 (site acquisition) + £1,500 (site rental) = £28,148

Cost saving with FWA relative to wholesale DSL alternative = £32,608 - £28,148 = = **£4,460 per 2 x 1.75 MHz or £2,548 per 2 x 1 MHz.**

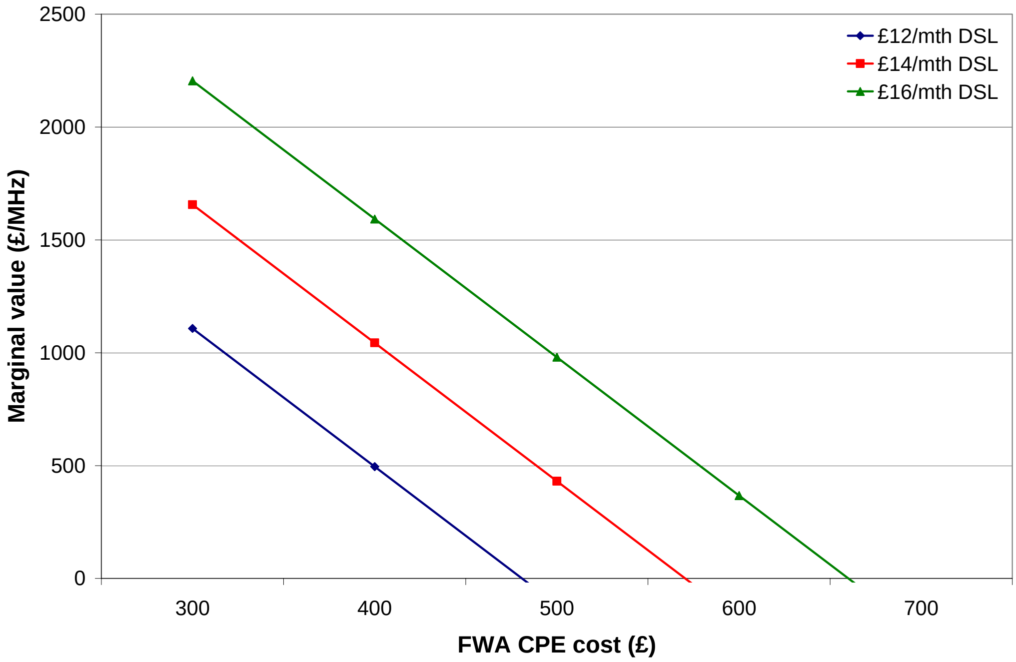
It is assumed that backhaul requirements for the two networks are similar and that cost differentials relate to the access network only. Note that this value is very dependent on the assumptions made about cost and service quality, some of which are subject to considerable uncertainty. For example, if the contention ratio is assumed to be 20:1 rather than 40:1 (competition is likely to drive down contention ratios over time) this would halve the number of customers that could be accommodated per sector and result in a significant reduction in the value of the spectrum, assuming costs remain the same:

- Total cost of ADSL service (80 subscribers) = £16,304
- Total cost of FWA per sector (80 subscribers) = £12,862 (equipment) + £925 (site acquisition) + £1,500 (site rental) = £15,287

Cost saving with FWA relative to wholesale DSL alternative (based on 20:1 contention) = £16,304 - £15,287 = **£1,017 per 2 x 1.75 MHz or £581 per 2 x 1 MHz.**

The sensitivity to cost assumptions are illustrated by the following graph which shows how the value might vary as a function of the assumed wholesale DSL tariff and FWA CPE cost: (based on 40:1 contention):

Figure A4.1



A4.3 Cost comparison based on business SDSL: bands up to 10 GHz

FWA System Assumptions:

- Base station bandwidth per sector: 2 x 1.75 MHz
- Total spectrum assigned to base station: 2 x 7 MHz (4 sectors each using 2 x 1.75 MHz)
- Modulation scheme: 16QAM
- Available bit rate (cumulative) per sector: 2 Mbit/s (2048 kbit/s)
- Nominal data rate to customer: 512 kbit/s @ 10:1 contention
- No. of subscribers (capacity) per sector: (2048/512)*10 = 40

Cost of using wholesale DSL alternative:

- Cost per wholesale DSL: £1,680 p.a. [112]
- Customer equipment cost = £500 = £134 p.a. (10% discount rate over 10 years and maintenance assumed to be 12% of capital)
- Total cost of wholesale DSL for 80 customers: (1,680 + 134) x 40 = £72,560 p.a.

Cost of deploying FWA:

- £1000 per subscriber for customer premises equipment (Aegis estimate)
- £200 per subscriber for base station equipment (Aegis estimate)
- Site acquisition: £25,000 per site = £6,250 per sector (4 sectors per site assumed) = £925 per annum
- Site rental: £6,000 per site = £1,500 per sector
- Total cost of equipment £1,200 (base station + CPE cost per customer) x 40 (no. of customers) = £48,000
- Equivalent annual cost of equipment = £12,862
- Total annual cost = £12,862 (equipment) + £925 (site acquisition) + £1,500 (site rental) = £14,287

Cost saving with FWA relative to wholesale DSL alternative = £72,560 - £14,287 = = **£58,273 per 2 x 1.75 MHz or £33,296 per 2 x 1 MHz.**

A4.4 Cost comparisons: 28 GHz

FWA System Assumptions:

- Base station bandwidth per sector: 2 x 28 MHz
- Total spectrum assigned to base station: 2 x 28 MHz (4 sectors)
- Modulation scheme: 16QAM
- Available bit rate (cumulative) per sector: 17 Mbit/s

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[112] based on BT IPStream Symmetric End User Access 500 (BT wholesale price list)

- Nominal data rate to customer: 1 Mbit/s committed
- No. of subscribers (capacity) per sector: 17

Cost of using leased line alternative: (BT Megastream 1)

- Connection: £9,000 per customer = £1,331 p.a. (BT Megastream 1)
- Rental: £3,032 p.a.
- Total cost of leased lines for 17 customers: 17 x (3,032 + 1,331) = £74,171.

Cost of deploying FWA:

- £2,500 capital per customer premises equipment (CPE) = £42,500 total for CPE (Aegis estimate)
- Base station cost = £100,000 per sector (Aegis estimate)
- Site acquisition: £25,000 per site = £6,250 per sector (4 sectors per site assumed) = £925 per annum
- Site rental: £6,000 per site = £1,500 per sector
- Total cost of equipment £142,500
- Equivalent annual cost of equipment = £38,182 (10% discount rate over 10 years and maintenance assumed to be 12% of capital)
- Total annual cost = £38,182 + £925 + £1,500 = £40,607

Cost saving with FWA relative to leased line alternative = £74,171 - £40,607 = = **£33,564 per 2 x 7 MHz or £4,796 per 2 x 1 MHz.**

Annex 5 Fixed Satellite Services

While of the view that the Smith-NERA methodology (basing satellite earth station fees on the basis of spectrum denial to fixed links) is still appropriate, we have endeavoured to determine a marginal value for FSS spectrum based on a least cost alternative. To do this, we considered what are the main choices that have to be made with regard to spectrum use given that the main requirement on a satellite link is to get an information bit rate from one location to another with a certain performance objective (e.g. Bit Error Rate - BER). There are in effect two choices that are interlinked and these are described below.

The first choice is the modulation / coding scheme that should be used. The BER is a requirement and can be satisfied by a number of modulation / coding schemes providing the necessary energy per information bit to noise density ratio (E_b/N_0) can be provided by the end-to-end link. The higher the level of modulation selected the higher the E_b/N_0 required and the less bandwidth required. At the same time the more coding applied the lower the E_b/N_0 required and the more bandwidth required.

The second choice, which is entirely dependent on the first choice, concerns the earth stations at either end of the link. The E_b/N_0 and bitrate (along with the characteristics of the satellite which can be considered to be provided as a fixed facility) will determine the EIRP required of the transmitting earth station and the figure of merit (G/T) of the receiving earth station in order to support the data rate on the link and meet the performance objective.

It can therefore be seen that the link designer can trade-off demodulator design (which determines the bandwidth required) against antenna gain, transmitter power and noise temperature to meet the performance objective at minimum cost.

This implies that the link designer can make a conscious decision to use less bandwidth at the expense of other factors and therefore administrative incentive pricing can be applied. The same argument can be applied to terrestrial systems but in the case of satellite base communications systems there is one characteristic that distorts the situation. The cost of launching and maintaining a satellite is so large that the cost of transponder capacity dominates a link designer's considerations. It is still the case that satellite transponders are transparent and generally power rather than bandwidth limited. Because of this one of the main objectives of a designer is to reduce the power requirement on the satellite as this is largely the basis on which the satellite user will be charged.

One of the main ways of reducing the power requirement is to use lower levels of modulation with a significant degree of coding, thereby giving a low E_b/N_0 target but at the expense of a higher bandwidth. For example, see the following characteristics in Table A5.1:

Table A5.1

Modulation / coding	E_b/N_0 (dB) (BER = 10^{-5})	Spectral efficiency (bps/Hz)
BPSK	9.6	1.0
BPSK & ½ rate Viterbi coding	4.4	0.5
BPSK, Reed-Solomon & ½ rate Viterbi coding	2.7	0.44

Source: Wertz and Larson – Space mission design and analysis

Note: The values in the table above are theoretical. However they are still relevant for comparison purposes.

It can be seen that adding ½ rate Viterbi coding reduces the power required by a factor of 3.3 (5.2 dB) but doubles the bandwidth required because of the additional coding bits. The addition of Reed Solomon coding as well reduces the power by a factor of 4.9 (6.9 dB) and increases the bandwidth required by a factor of 2.3 (both relative to the straight BPSK).

The general case that satellites are power limited rather than bandwidth limited is supported by the observation that link designers are driven towards significant levels of coding in order to make the link technically supportable and to keep the cost down.

For the sake of the argument, if a 36 MHz transponder at Ku-band is assumed to have an annual rental of £1.5 million,[113] then it is reasonable to assume (without going into any power/bandwidth apportionment arguments) that a 5 MHz carrier, for example could cost the order of £200,000 per annum.

If this carrier is being supported by a straight BPSK carrier and the transponder is power limited the link designer will probably choose to add ½ rate Viterbi coding. As noted earlier this would decrease the satellite power requirement by a factor of 3.3 but double the bandwidth required. As the transponder is transparent there is also the beneficial side effect of the earth station EIRP requirement being reduced by the same amount. Because the transponder is power limited it might be assumed that the new charge for the carrier would be £200,000 / 3.3 = £60,000 p.a., a reduction of some £140,000 p.a.

From an administrative incentive pricing point of view this means that in order to encourage the system designer to use the spectrum efficiently (i.e. move back to straight BPSK using half the bandwidth) the price would have to be set at a level of £140,000 p.a. for 5 MHz in this example.

[113] See *Guide to satellite systems cost modelling*, Ovum report for RA, September 2002.

Annex 6 Cellular

A6.1 Introduction

For GSM networks the value of spectrum depends very much on the assumptions made about the network, in particular the level of traffic on the network and how the traffic is distributed. In practice, a minimum "core" amount of spectrum is required to provide the necessary geographic coverage – in theory this could be as low as 2 x 2.4 MHz but in practice is more likely to be in the range 2 x 9.6 – 2 x 15 MHz.[114] Beyond this core amount, additional spectrum is used to provide additional capacity in areas of high demand. The alternative to using additional spectrum is to deploy smaller cells in the areas of high demand and increase the number of base stations, adding to the overall infrastructure costs (since it is significantly cheaper to deploy additional frequencies at existing sites than to commission new sites from scratch).

The extent of the areas of high demand where additional spectrum might be deployed will decline progressively once the core spectrum required for coverage is exceeded. For example, the first additional block of spectrum beyond the minimum required for coverage might be required at up to 60% of sites, whereas the next block might only be required at 40% of sites and so on, due to the highly concentrated nature of traffic "hot spots".

For the purposes of our calculations, we have assumed that the minimum marginal change in spectrum assigned to an operator would correspond to that required for a single radio channel per sector to be used throughout a cell cluster.

A6.2 Cost calculations

Assuming a typical 3 x 4 cell re-use pattern (i.e. a cluster comprising four tri-sectored cells) and a single radio channel per sector throughout a cell cluster, this equates to (200 kHz x 3 x 4) = 2.4 MHz of paired spectrum. We have further assumed that the maximum number of radio transceivers that can be accommodated per sector is four (based on manufacturers' data – this tends to be a physical limit based on cabinet size etc).

Hence the comparison is between sufficient spectrum to provide three transceivers per sector and four transceivers per sector, i.e. between 2 x 7.2 and 2 x 9.6 MHz. To overcome the physical limitation on the number of transceivers per sector, it is assumed that the networks use a multi-layer cellular plan, each layer capable of using up to 2 x 9.6 MHz of spectrum. Since the operators in the UK have between 2 x 23 and 2 x 30 MHz of spectrum, this means at least three layers will be available in the areas of highest demand and we have therefore assumed that one third of the traffic in these areas will be carried on each layer.

The following costs are based on data from the Oftel LRIC model for GSM networks.

- Total cost per new base station site (3 sector macrocell):
  - Site acquisition cost: £25,000 total = £8,333 per sector = £1,233 per annum (10% discount over 10 years)
  - Equipment capital cost: £33,000 per sector = £4,882 per annum
  - Equipment maintenance cost (12% of capital): £3,960 per annum

[114] Based on ERO Report "Traffic Loading of GSM Networks", April 1998

- Site rental: £6,000 = £2,000 per sector per annum

- Capital cost for additional radio equipment at existing sector (to utilise additional spectrum): £5,880 = £870 per annum.
- Maintenance cost for additional radio equipment = £705 per annum
- Total busy hour traffic on network: 128,000 Erlangs (estimate for 2003/04 from Oftel LRIC model)
- Proportion of traffic in high demand areas (i.e. where spectrum requirement exceeds that required for core coverage): 50%
- Total traffic demand in areas of high demand: 64,000 Erlangs
- Total traffic per cellular layer in these areas: 21,330 Erlangs (i.e. one third of total)

Table A6.1 Calculation of number of sectors required in layer under consideration

	Without extra spectrum	With extra spectrum	Change
Spectrum available	2 x 7.2 MHz	2 x 9.6 MHz	2 x 2.4 MHz
RF channels per sector (N)	3	4	1
GSM traffic channels per sector (8N – 1)	23	31	8
Capacity per sector (Erlangs)*	14.5	21.2	-
No. of sectors required	1,471	1,006	465

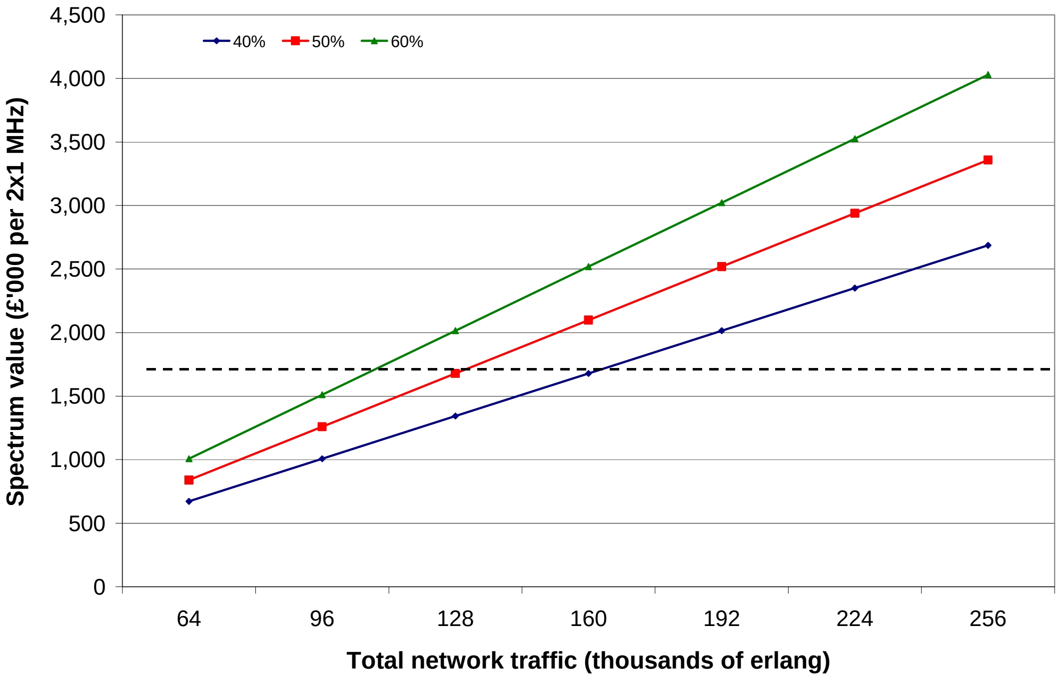
*assuming 1% call blocking probability (from Erlang B formula)

The calculations of the costs of the two options are as follows:

- Cost of additional radios at existing sites if extra spectrum used:
  - Capital cost: 1,006 x £870 = £875,220 p.a.
  - Maintenance cost: 1,006 x £705 = £709,230 p.a.
  - **Total cost of additional radios = £1,584,450 p.a.**
- Cost of additional sectors in lieu of spectrum:
  - Site acquisition cost = 465 x £1,233 = £573,345 p.a.
  - Equipment capital cost = 465 x £4,882= £2,270,130 p.a.
  - Equipment maintenance cost = 464 x 3,960 = £1,837,440 p.a.
  - Site rental = 465 x £2,000 = £930,000 p.a.
  - **Total cost of additional sectors = £5,610,915 p.a.**
- Difference in cost = (£5,610,915 - £1,584,450) = £4,026,465
- **Difference in cost** per 2 x 1 MHz = £4,026,465 / 2.4 = £1,677,694

As previously noted, this marginal value is very dependent on the assumptions made about the traffic volume and distribution. The following graph indicates the variation in value as the traffic volume is increased by +/- 50% and where the proportion of total network traffic carried in the high demand areas (where extra spectrum would be deployed) varies between 40% and 60%.

Figure A6.1 Relationship between spectrum value and traffic volume / distribution



(% figure refers to proportion of total busy hour network traffic carried in areas of highest demand, i.e. where additional spectrum would be utilised)

Annex 7 Public Access Mobile Radio

A7.1 Introduction

Our approach to determining the marginal value of PAMR spectrum is to consider the impact that a small increase in spectrum would have on the infrastructure requirement of a PAMR operator. It is assumed that the PAMR spectrum requirement is driven by the areas of highest traffic demand, namely inside the M25 ring and in a few other key urban areas. The minimum coverage requirement for a national network is assumed to be 90% of the population, requiring around 600 cell sites for coverage alone. Additional sites are required to provide additional capacity in areas of high demand, and the number of these additional sites will depend upon the amount of spectrum available to the user. This enables the cost trade-off between additional spectrum and additional infrastructure to be determined, from which a notional spectrum value may be obtained.

A7.2 Minimum marginal spectrum increment

The minimum marginal spectrum increment is assumed to correspond to the addition of a single radio transceiver to each base station sector in the high demand areas. A cell cluster size of 40 has been assumed, based on discussion with RA, and this corresponds to a spectrum requirement of 40 paired 25 kHz channels = 2 x 1 MHz total. An initial spectrum assignment of 2 x 4 MHz has been assumed, i.e. the marginal increase in spectrum would take this to 2 x 5 MHz.

A7.3 Assumed traffic levels

Spectrum value will depend very much on the assumed level of traffic in the network, as this determines how much additional infrastructure will be required in the absence of additional spectrum. For our initial calculation, we have assumed a total customer base of 100,000 and an average busy hour traffic level of 20 milli-erlangs per subscriber, i.e. total network traffic of 2,000 erlangs. Based on discussion with the RA we have assumed that around 50% of the busy hour traffic (i.e. 1,000 erlangs) will be located in the high demand areas where the additional spectrum would be deployed.

A7.4 Calculation of spectrum and infrastructure requirements

- Assuming a spectrum assignment of 2 x 4 MHz and a cell cluster size of 40 (= 1 MHz per cluster), 4 carriers per sector are available, i.e. 15 traffic channels + 1 control channel per sector (assuming TETRA is being deployed).
- Assuming a 1.3 % probability of a delay of 0.2 second in accessing a channel, 15 traffic channels translates into 7.5 erlangs (Erlang C formula).
- The number of cell sectors can be determined by dividing the total traffic demand (1,000 Erlang) by the capacity of each sector (7.5 Erlang), which results in a requirement for 134 sectors.

The impact of additional spectrum is to reduce the number of sectors required. If the spectrum assignment is increased by 2 x 1 MHz to 2 x 5 MHz, the network would be able to accommodate 5 carriers per sector, i.e. 19 traffic channels per sector which equates to 10.5 erlangs / sector. So the number of sectors required in the high demand areas would fall to (1,000 / 10.5) = 96 sectors, a reduction of 38 sectors relative to the 2 x 4 MHz scenario.

A7.5 Calculation of infrastructure cost saving arising from extra 2 x 1 MHz spectrum assignment

We have assumed the following costs in our calculations:

- Base station capital costs: £100,000 per sector including a single transceiver + £20,000 per additional transceiver, i.e. £160,000 per sector based on four transceivers (i.e. 2 x 4 MHz)
- Annualised capital cost of base station per sector = £23,672 p.a. (assuming a 10% discount rate over 10 years).
- Annualised cost of additional transceiver where additional spectrum used = £2,959 p.a.
- Site acquisition cost = £25,000 = £8,333 per sector = £1,233 p.a. per sector (based on value for GSM macrocell site in Oftel LRIC model for GSM networks)
- Equipment maintenance costs at 12 % of capital = £19,200 p.a. (sector with four transceivers), or £2,400 p.a. for an additional transceiver
- Site rental: £6,000 p.a. per site = £2,000 p.a. per sector for a tri-sectored site
- Communication links cost £1500 p.a. per site = £500 per sector plus £250 per transceiver = £1,500 p.a. for a sector with four carriers.

The cost of additional infrastructure in the absence of extra spectrum is as follows:

- 38 extra sectors required with 4 carriers per sector
- Base station capital cost = (38 x £23,672) = £899,536 p.a.
- Site acquisition cost = (38 x £1,233) = £46,854 p.a.
- Equipment maintenance cost = (38 x £19,200) = £729,600
- Site rental = (38 x £2,000) = £76,000 p.a.
- Communication links = (38 x 1,500) = £57,000
- Total cost = £1,808,990 p.a.

The cost of additional transceivers at existing sites assuming extra 2 x 1 MHz available is:

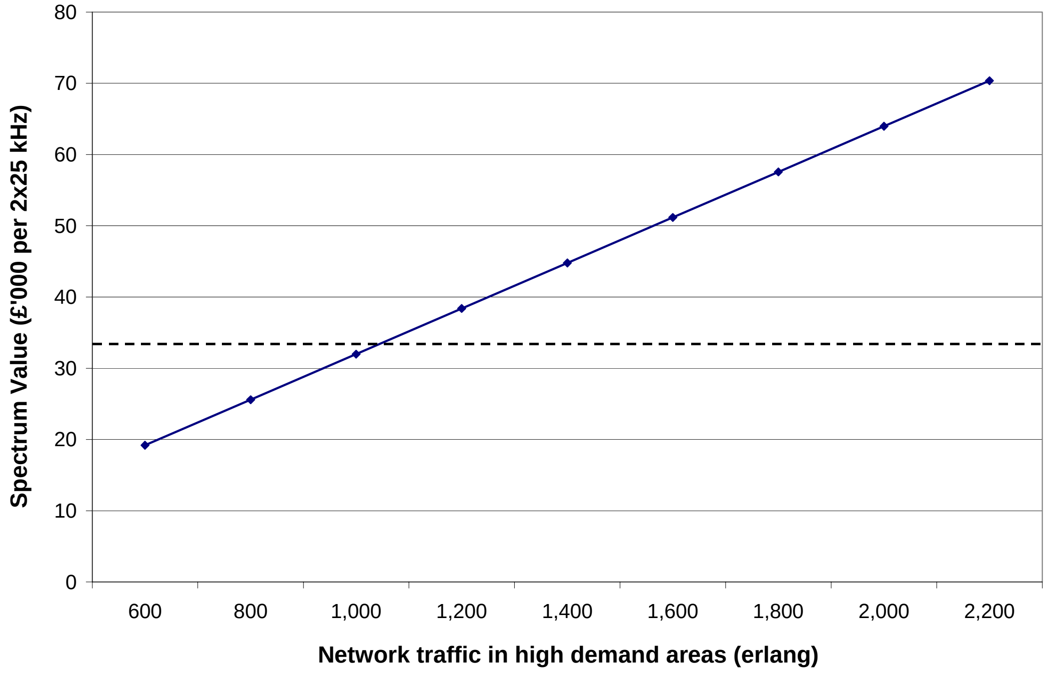
- 96 sectors require extra transceiver
- Transceiver capital cost = (96 x £2,959) = £284,064
- Transceiver maintenance cost = (96 x £2,400) = £230,400
- Communication link for extra transceivers = (96 x £250) = £24,000 p.a.
- Total cost = £538,464

The difference in cost = £1,808,990 - £538,464 = **£1,270,526**

The difference in cost per 2 x 25 kHz channel = £31,763.

Note that this value is very dependent on the assumed level of traffic on the network, as the following graph illustrates:

Figure A7.1 Marginal Spectrum Value for PAMR as a function of Network Traffic in high demand areas



Annex 8 Private Mobile Radio

A8.1 Introduction

Our approach to determining the marginal value of PMR spectrum is based on the assumption that the least cost alternative for the use of a congested frequency band is to switch to an alternative, uncongested frequency band. In practice this might, for example, mean users in a congested band such as VHF mid-band or the 450 – 470 MHz band moving to an uncongested band such as Band III or VHF low band. This would involve replacing existing radio equipment (base stations and mobiles) halfway through its useful life, i.e. after five years rather than ten.

We have considered the lowest cost alternative for a variety of typical PMR systems, based on data from the Agency's licensing database.

The systems considered were as follows:

Table A8.1

System type:	A	B	C	D	E	F	G
Base Stations	2	1	2	3	7	18	25
Mobiles	10	100	200	490	1820	2000	3600
Frequencies	1	1	1	3	8	8	14
Assignments	2	1	2	3	8	22	25
Mobs/freq	10	100	200	163	228	250	257

Two alternatives were considered in each case, namely switching to a PAMR service and migrating to an alternative, uncongested frequency band. The other alternatives considered in the original Smiths-NERA study were also considered but were rejected on the following grounds:

- Cellular was rejected on the following grounds that cellular in its current form would not provide the necessary functionality for most PMR users, particularly with regard to fixed monthly costs and "push to talk" communications.
- Narrow band technology was rejected, on the grounds that the technology has failed to become established in the marketplace and there remains only one supplier.
- CBS was rejected as the nature of CBS services (typically a single base station with no more than 2 – 3 frequencies, often only one) means they are not suitable for supporting large users with sufficient mobiles to justify an exclusive PMR channel. They may provide a viable alternative to smaller users operating on shared channels, but even then the coverage is unlikely precisely to match the user's requirement.

For the smallest system type (A), we determined that there would in fact be a cost saving by moving to PAMR, due to the relatively high cost of deploying two base stations with only ten mobiles. In all other cases, the lowest cost alternative was found to be migration to an alternative band, with the cost of such migration being lowest for an operator with a single base station and 100 mobiles.

The extent to which a PMR channel may be considered fully occupied depends upon the traffic profile of the system (frequency of calls, call duration etc). The Agency currently defines four broad user categories in its fee regulation, reflecting these different traffic profiles and defining a different threshold for the maximum fee chargeable in each case (i.e. where a channel is assumed to be fully loaded and therefore not suitable for sharing with another user). The threshold figure for taxis, minicab and courier companies is 113 mobiles per channel location and for other non-data dominant private business users the threshold is 75. We therefore consider that the figure of 100 mobiles per assigned channel location, as assumed for system type B above, is a reasonable benchmark for the efficient use of a PMR channels and consequently we decided to base the marginal valuation for PMR spectrum on the cost that would be incurred by an operator of system type B migrating to another band.

A8.2 Cost assumptions

The following generic cost estimates for a PMR system from European Communications Committee Report 105 have been used in our calculations; the costs are assumed to be independent of frequency band:

- Base station: £1500
- Site costs for base station: £1000 per year (average)
- Mobile station: £150-250 (£200 average)
- Land line: £300 per line
- Batteries, maintenance for mobiles: £50 per terminal per year
- Electrical power: £300 per base station per year

It is assumed that a typical PMR channel should be able to support at least 100 mobiles (see above). Larger systems tend to be more efficient in their use of spectrum and may support several hundred mobiles per assigned frequency, particularly where trunking techniques are employed. Such systems will therefore incur a higher cost per unit of assigned spectrum in moving to an alternative band, but as such systems are clearly more efficient in their use of spectrum it would be counter-productive to apply a higher spectrum valuation on this basis. We have therefore based our spectrum valuation on the cost that would be incurred by a user with a single frequency assignment operating one base station and one hundred mobiles in moving to an alternative frequency band.

A8.3 Determination of marginal value

In moving to another band, it is assumed that equipment will be replaced halfway through its useful life, i.e. after five years rather than ten. At this point, the equipment will have depreciated to half its original value and we assume that this residual value that is written off will be amortised over the remaining five year period. The valuation is thus determined as follows, using the cost data from ECC Report 105:

- Original base station cost: £1,500
- Depreciated value of base station: £750
- Annualised value of base station (10% discount rate over 5 years): £180
- Original mobile cost: 100 x £200 = £20,000
- Depreciated value of mobiles = £10,000
- Annualised value of mobiles = £2,398

- Total annualised cost of moving to alternative band = £180 +£2,398 = £2,578.

This value is based on a single PMR base station with a notional coverage area of 30 km radius and which sterilises an area of notionally 60 km radius.

Annex 9 TV

A9.1 Introduction

This Annex sets out several options for deriving the opportunity cost of UHF TV spectrum based on opportunity cost of spectrum to analogue and digital broadcasters.

A9.2 Analogue TV

In the case of analogue we consider removal of a single 4-channel grouping. Each main analogue TV transmitter operates on one of 9 standard groups of 4 frequency channels which are re-used at a number of locations around the UK. We estimated the cumulative population served by each of the channel groups and used the group that served the lowest population as the basis of our calculation. This is consistent with our general approach that where a range of AIP values exists a value towards the lower end of the range should be chosen. In this case we estimate that the difference between the lowest and highest values would be approximately 2:1.

It is assumed that the channel grouping corresponding to the lowest incremental coverage would be chosen and that in parts of the coverage area reception would be available from adjacent transmitters (though reception by portables may be lost and re-alignment or replacement of aerials may be needed in some cases). Current penetration of cable and satellite, estimated at 30% of TV households, is assumed.

Removal of channel group F (comprising channels 41, 44, 47 and 51) would result in loss of coverage from the following transmitters:

Table A9.1

Transmitter	Coverage (pop '000s)[115]
Emley Moor (Yorks)	4,000
Wenvoe (S Wales)	800
Sudbury (Suffolk)	600
Redruth (Cornwall)	100
Londonderry	100
+7 low power relays	200
Total	5,800
Less 30% already with cable/satellite	1,740
Net Population coverage loss	4,060
Equivalent TV households	1,740

We assume approximately 25% of those affected would be able to obtain terrestrial reception via adjacent or relay transmitters. Hence around 1.3M households would lose terrestrial coverage altogether.

[115] Aegis estimate.

Assuming a total annual cost for satellite / cable provision of £24.80 per household (as above), the total annual cost of providing alternative reception in the affected areas would be (£24.80 x 1.3M) = £32.2M. The costs associated with maintaining four high power analogue transmitters, including site rental, maintenance etc should be deducted – we do not currently have accurate information on this but estimate it would be of the order of £1M per annum in total, i.e. the net cost would be £31.2M. Since a total of four channels would be released (i.e. 32 MHz) the cost per MHz per annum would be approximately £1M.

In practice some households may be able to receive services over DTT and this may reduce our estimates, depending on the extent of DTT coverage and whether households would need new aerials as well as a set top box. However, the estimates make no allowance for the loss of reception for second and third sets in each household, which would tend to increase the value.

A9.3 Digital TV

For digital, we consider a reduction from 6 channels per multiplex to 5 channels per multiplex, for the two public service multiplexes post-switchover. This option was considered in the 2002 DTI/DCMS consultation on the Principles for DTT Spectrum Planning[116] and was estimated to correspond to a reduction in population coverage from 95% to 90%. Cable and satellite penetration of 35% at switchover is assumed.

According to the 2002 DTI/DCMS consultation, reducing the number of channels per digital multiplex from 6 to 5 would reduce coverage from 95% to 90%. This is estimated to be equivalent to a loss of coverage for 1.29 million TV households.[117] Assuming that by the time of switchover 35% of households have access to digital cable or satellite, it would be necessary to provide alternative reception to an extra 845,000 households. Assuming a capital cost of providing satellite or cable access to these households to be £100 each, this equates to an equivalent annual cost (10% discount over 10 years) of £14.80. A further £10 per year per household is assumed to cover maintenance and update of smart cards for access to the satellite / cable service. This equates to a total cost of £20.95M. It is assumed that as a result of the reduced coverage at least four fewer high power DTT transmitters would be required. This would lead to a capital cost saving of £1.6M per site[118] = £6.4M total = £765,000 per annum equivalent (10% over 15 years). A further £1M per annum total saving in site and maintenance costs is also assumed. Hence the net cost would be (£20.95M - £1.765M) = £19.2M. Since a total of two channels would be released (i.e. 16 MHz), the cost per MHz per annum would be approximately £1.2M.

[116] Available at http://www.digitaltelevision.gov.uk/pdfs/spectrum_planning_digital_TV.pdf

[117] Assuming 25.7M TV households in UK (source: Media Guardian.co.uk, 3/5/03)

[118] Source: DTI/DCMS consultation document on DTT spectrum planning.

Annex 10 Aeronautical Communications

Our approach to determining the marginal value for aeronautical mobile spectrum is based on the assumption that operators could migrate from the current 25 kHz bandwidth technology to 8.33 kHz, resulting in approximately 50% reduction in spectrum utilisation after frequency re-use considerations are taken into account.

There are currently 2,300 licensed ground stations in the UK (see Table A10.1) and 7,500 aircraft stations. Of the latter, 1,300 are commercial aircraft that have already upgraded to narrow band equipment, hence there are 6,200 that would require upgrading.

Table A10.1 Aeronautical Ground Station Statistics.

Ground Station type	No. of stations
NATS Air Traffic Control	300
Other Air Traffic Control Providers	229
Operations Control (catering for private use)	785
General Aviation (catering for balloons, gliders etc)	313
Aero information services:	120
Others	553
Total	2,300

note: a ground station is considered to be a single frequency at a single site, hence deployment of x frequencies at the same site would equate to x stations

We have identified the price of a typical 8.33 kHz compatible aircraft transceiver as approximately £3,225, compared to a comparable non-compatible receiver which is £2,380,[119] i.e. a differential of £845. Assuming that this additional cost would have to be borne by all aircraft, this would imply a total upgrading cost of (6,200 x £845) = £5.24m

The estimated cost of upgrading an existing air traffic control ground station, based on information provided by NATS, is £75,000 per station. It is estimated that up to 20% of these stations would need to retain 25 kHz operation due to operational constraints, such as the need to accommodate international military aircraft traversing UK commercial airspace. Hence around 470 (=80% of 529) ground stations would be suitable for upgrading, at a total cost of (£75,000 x 470) = £35.25m.

We have not been able to identify cost data for other types of aeronautical ground station, hence we have performed three calculations based on the following cost estimates for these stations. In each case it has been assumed that 20% of these stations cannot be upgraded due to operational constraints, as noted above in the context of ATC stations. Hence a total of 1,416 upgradeable non-ATC stations has been assumed in each case

- Option 1: assumes average cost of upgrading non-ATC ground stations equates to cost of upgrading aircraft stations (£845)
- Option 2: assumes average cost of upgrading non-ATC ground stations equates to cost of a TETRA PAMR transceiver (i.e. £20,000 per station)
- Option 3: assumes average cost of upgrading non-ATC ground stations equates to cost of upgrading ATC stations (i.e. £75,000 per station)

[119] Based on Bendix-King models KY 196B and KY 1906B respectively

Calculated marginal values are presented in Table A10.2. Note that in determining the per MHz value we have assumed a 50% reduction in the spectrum utilisation with narrow band equipment, i.e. total cost has been divided by half of the available spectrum, or 9.5 kHz:

Table A10.2

Cost element	**Option 1**	**Option 2**	**Option 3**
ATC station upgrade	£35.25m	£35.25m	£35.25m
Non-ATC station upgrade	£1.20m	£28.32m	£106.2m
Aircraft station upgrade	£5.24m	£5.24m	£5.24m
Total cost	£41.69m	£68.81m	£146.69m
Annualised total	£4.45m	£7.35m	£15.66m
Cost per MHz	£468,000	£773,000	£1.65m
Cost per 25 kHz	£11,700	£19,340	£41,210